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Research and Development Technical Report
ECOM-3319

BROADBAND HORNS

by

John L. Kerr

August 1970

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

ECOM - 3319

BROADBAND HORNS

By

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Radar Technical Area
Combat Surveillance, Target Acquisition and Systems Integration Laboratory

August 1970

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UNITED STATES ARMY ELECTRONICS COMMAND, FORT MONMOUTH, NEW JERSEY

ABSTRACT

This report describes the development of two very broadband horn antennas using double-ridged waveguide techniques. The first design accomplished was that of a feed horn to be used to illuminate a six-foot parabolic reflector over the frequency range from 1 GHz to 12 GHz. Pattern data show that the beamwidth of this horn design rapidly becomes narrower than would normally be considered acceptable for that purpose. However, that was considered to be useful for the intended application since it was required that the half-power beamwidth from the six-foot parabola not become less than two degrees. That indicates that only about one half of the reflector should be illuminated at the upper frequency limit.

The second development consisted of designing a larger horn with a nominal gain of approximately 15 db and with a significant requirement that the gain variation be held to a minimum over the frequency range. The technique used to reduce the gain variation consisted of using relatively large flare angles to introduce increasingly greater phase error with increasing frequency and thus reduce the aperture efficiency.

Electrical performance characteristics are presented for the two horn designs as well as data measured with the feed horn illuminating a six-foot parabolic reflector.

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BROADBAND HORNS

INTRODUCTION

Over the past several years, personnel of this Laboratory have been engaged in the development of various broadband horn antennas using double-ridged waveguide techniques.[1] The very early work, for countermeasures applications, began more than a decade ago and resulted in the development of several feed horns which exhibited bandwidths of slightly more than three to one. During that effort, the possibility of achieving greatly increased bandwidth was recognized but little additional work was done for a period of some six years. Increased bandwidth requirements, for radio frequency interference measurements, revived the program and resulted in the design of a feed horn having a six-to-one bandwidth, covering the frequency range from 1.8 GHz to 10.8 GHz. That horn was used to illuminate a four-foot parabolic reflector which served as an interim high-gain antenna.

Since it was still the goal to cover the entire frequency range from 1 GHz to 12 GHz with a single antenna, additional effort was directed toward further increasing the bandwidth. This more recent work, also for RFI application, has resulted in achieving bandwidths in excess of twelve to one for two horn designs to meet separate sets of requirements in the 1 GHz to 12 GHz frequency range.

The first design accomplished was that of a feed horn to be used to illuminate a six-foot parabolic reflector for high-gain applications. In addition to the high-gain antenna, the need existed for a moderate-gain antenna with a minimum of gain variation over the band of interest.

DESCRIPTION (Broadband Feed Horn)

The broadband feed horn (Figure 1) consists of a short section (about 1.5 inches) of S-band waveguide with inner dimensions of 2.84 inches by 1.34 inches. Tapered inserts are used to reduce the width of the waveguide from 2.84 inches to 1.39 inches in the region from the center line of the coaxial input feed point to a shorting plate which is 0.325 inches away (to the left in Figure 1). The width increases from 1.39 inches at the feed point to the full guide width of 2.84 inches at the waveguide-horn junction which is axially one inch away (to the right in Figure 1). The height of the waveguide remains constant at 1.34 inches throughout.

The tapered section of the horn has an axial length of 12 inches. The inside dimensions increase from 2.84 inches by 1.34 inches at the throat to 7.5 inches in the H-plane by 5.2 inches in the E-plane at the aperture. The ridges are fabricated of 0.375-inch thick aluminum plate and are dimensioned so that the spacing between them increases logarithmically from 0.050 inches at the waveguide-horn junction to 5.2 inches at the aperture plane of the horn.

Figure 2 is a photograph of the development model. Figure 3 is the graph from which the ridge curvature was determined. The X-coordinates are axial distances measured along the center line of the antenna with X = 0 being located at the plane of the waveguide-horn junction. The Y-coordinates are perpendicular distances from the center line of the antenna to the ridge surface. As indicated on the graph, an additional linear taper is superimposed on the logarithmic curve.

MEASURED CHARACTERISTICS (Broadband Feed Horn)

The electrical performance characteristics of the broadband feed horn were determined by measuring VSWR, radiation patterns, and gain over the 1 GHz to 12 GHz frequency range.

During the early stages of the development, an attempt was made to limit the axial length of the feed horn to six inches. VSWR readings were found to be somewhat higher than desired in the 1 GHz to 2 GHz range. The high values were thought to be due to the short length of the transition and therefore the axial length was gradually increased to twelve inches in an attempt to improve the performance in that region. Near the end of the development of the longer model, it was determined that addition of a small linear taper superimposed on the logarithmic curve provided a substantial improvement in the VSWR at the lower end of the band and had little effect elsewhere. The amount of additional linear taper has varied for different horn configurations and was found to be 0.008X inches for optimum results in this design. VSWR measurements also revealed a very high peak (greater than seven to one) at 8.8 GHz. Two small metal pins, making contact with the back shorting plate and approximately the center of the back edge of each ridge, were used to effectively suppress the very high reflection. The exact reason for the high VSWR was not determined. It was most likely due to moding or a resonance effect in the back cavity since it is quite large in terms of wavelength at the frequency of peak VSWR. The pins tend to increase the VSWR slightly at the lower end of the frequency range but not enough to be of any concern. Figure 28 shows the VSWR and gain as measured on the development model. Figures 4 through 27 are typical E- and H-plane patterns plotted on a relative voltage scale. It can readily be seen that the beamwidth of the horn rapidly becomes narrower than would normally be considered appropriate for illuminating a parabolic reflector with a focal length-to-diameter ratio of one half. That was not considered to be detrimental for the intended application since it was required that the half-power beamwidth of the high-gain antenna not become less than two degrees at the upper end of the frequency range. From that point of view, approximately one half of the parabola should be illuminated at 12 GHz.

MEASURED CHARACTERISTICS (6-Foot Parabola - Broadband Feed Horn)

In order to meet the requirements for a broadband, high-gain antenna the horn was used to illuminate a six-foot parabolic reflector with a focal length to diameter ratio of one half. The feed position along the focal axis was first optimized for operation in the mid-band region around 5 GHz. Pattern measurements with the feed at that location showed main lobe splitting above 10 GHz. The feed was then repositioned along the axis to a point which gave best results at 11 GHz. That position produced usable pattern data over

the entire 1 GHz to 12 GHz frequency range and appeared to be the best compromise available. This final location resulted in having the aperture plane of the feed horn slightly more than three inches inside the focal point of the parabola. The same horn design was later used in another application where the frequency range of interest was limited to the 1 GHz to 2 GHz band. Optimizing the focal position for that range resulted in having the aperture plane of the horn located at the focus of the parabola. This gives an indication of how the location of the phase center of this horn design changes over such a large frequency range. That is not surprising considering that the size of the horn is such that it represents little more than an open-ended waveguide at 1 GHz but is a rather long horn with a relatively large aperture at the higher frequencies.

Figures 29 through 42 are representative E- and H-plane patterns over the range of interest. The patterns from 4 GHz to 12 GHz show far-out side lobes and/or back lobes. These are due to various sources of reflection which were present on an improvised range being used at the time to meet the distance requirement in that frequency range. The patterns at 1 GHz and 2 GHz were measured on another range which did not have that problem. The large amount of spillover apparent on Figure 29 is due to the very wide beamwidth of the E-plane pattern of the feed horn (Figure 4). Although the broadband horn patterns narrow considerably in the upper portion of the band, it can be seen that the half-power beamwidth of the high-gain antenna has not been maintained at two degrees or more at some of the higher frequencies. Figure 43 shows the side-lobe level and gain over the frequency range. The gain curve includes the loss incurred in using a 4.5-foot length of RG9B/U feed cable as well as losses due to the non-optimum location of the phase center of the feed horn at various frequencies.

DESCRIPTION (Moderate-Gain Horn)

In addition to the high-gain antenna just described, a requirement also existed for a moderate-gain antenna (on the order of 15 db) with the gain variation over the band held to a minimum. From an aperture point of view, assuming a constant aperture distribution over the twelve-to-one band, the gain variation would be approximately 21.6 db. In the case of horn antennas constant aperture distribution is not the case since phase error increases with increasing frequency. That is, for optimum results[2] in horns with relatively large apertures, long axial lengths with small flare angles are required. The approach used here to minimize the gain variation was the use of rather large flare angles. That introduces increasingly greater phase error across the aperture as frequency is increased and results in lowered aperture efficiency in the upper portion of the band. Based on observation of pattern performance of various double-ridged horns, it appeared that perhaps the larger flare angles could be utilized without experiencing the pattern deterioration observed in ordinary pyramidal horns: particularly in the E-plane. Another very broadband antenna[3] has been developed based on the above observation and the fact that it was noted during the development of the moderate-gain horn that the VSWR was not greatly affected when the horn sides were removed.

The moderate-gain horn (Figure 44) consists of a short section (about 1.5 inches) of double-ridged waveguide with a coaxial input. The waveguide at the feed point is 1.4 inches wide by 0.872 inches high. That cross section is

maintained for a distance of 0.325 inches back to a shorting plate (to the left in Figure 44). It is interesting to note that both the cross section of the launcher and the length of the back cavity are extremely small, with the length of the cavity being about an order of magnitude shorter than usual for operation at the low end of the frequency range. The size of the cavity increases from 1.4 inches by 0.072 inches at the feed point to 3.4 inches by 2.616 inches at the waveguide-horn junction which is one inch from the feed point (to the right in Figure 44). The horn section has an axial length of 18 inches and an aperture of 15 inches in the H-plane by 12 inches in the E-plane. The distance between the ridge surfaces increases from 0.050 inches at the waveguide-horn junction to 12 inches at the aperture plane of the horn. Figure 45 is a photograph of the development model. Figure 46 is the graph from which the ridge curvature was determined. Note that in this design the amount of additional linear taper is 0.011X inches rather than 0.008X inches as was the case for the feed horn.

MEASURED CHARACTERISTICS (Moderate-Gain Horn)

The initial model fabricated for this development utilized the S-band waveguide launcher described earlier for the feed horn. Preliminary pattern measurements indicated pattern deterioration above 10 GHz. Investigation of this problem pointed to the waveguide launcher as being a major source of the trouble and led to a complete redesign. The waveguide launcher just described permitted operation to 12 GHz. The reduced height of the cavity also eliminated the need for the mode-suppressing pins as required in the broadband feed horn.

Typical E- and H-plane radiation patterns, plotted on a relative voltage scale, are shown in Figures 47 through 70. Figure 71 shows the VSWR and gain over the 1 GHz to 12 GHz band. As can be seen from the gain curve, the variation is approximately seven db over the twelve-to-one frequency range. It is interesting to compare the gain curves for the feed horn and the moderate-gain horn (Figures 28 and 71). Although the aperture area of the moderate-gain horn is more than four times that of the feed horn, the maximum gains are about equal: indicating that some measure of success has been achieved in reduction in aperture efficiency On the other hand, at lower frequencies, where the phase error is less severe, the moderate-gain horn shows a substantial increase in gain over the feed horn.

CONCLUSIONS

Two very broadband horn designs have been accomplished. Both cover the frequency range from 1 GHz to 12 GHz and have performance characteristics which are acceptable for the intended applications. For many purposes the feed horn beamwidth rapidly becomes narrower than would usually be considered acceptable. In addition, there is a significant shift in the location of the phase center of the horn over the frequency range. That leads to losses w are due to the fact that the focal position chosen represents a compromis The moderate-gain horn was made to operate over the twelve-to-one band b e-design of the waveguide launcher. The gain variation was held to approx mately 7 db by using relatively large horn angles so that the increasing phase error over the band reduced the aperture efficiency at higher frequencies.

As stated earlier in the report, it was found that a small linear taper superimposed on the logarithmic ridge curve tended to give a substantial improvement in VSWR in the first octave of the bandwidth. This led to the thought that the axial length of the feed horn could be reduced. That was found to be so in a model with an axial length of six inches.

It is now felt that the problems of narrowing beamwidth and shifting phase center associated with the feed horn can be alleviated to some extent by the short axial length design. It also appears likely that the gain variation of the moderate-gain horn can be further reduced for applications requiring more nearly constant gain.

In addition to the above possibilities, other developments based on the six-inch axial length design have been accomplished. These are to be the subject of a future report.

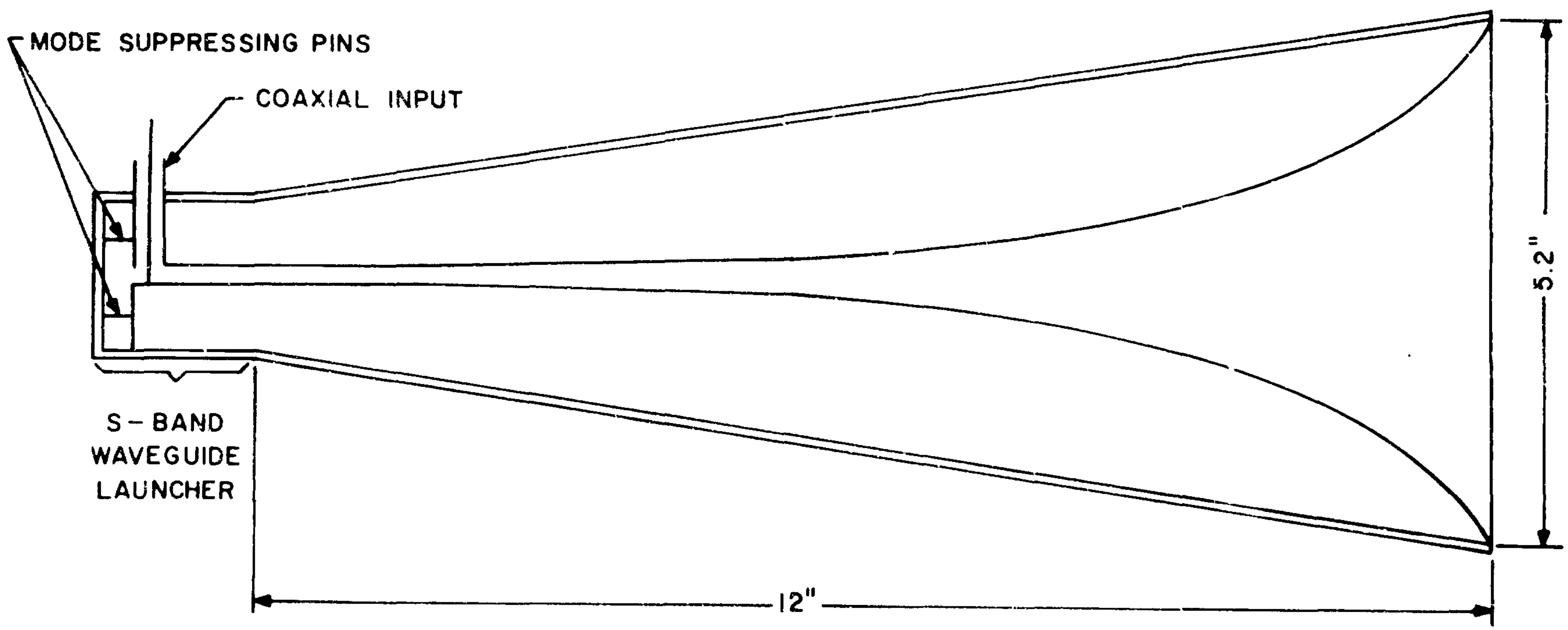
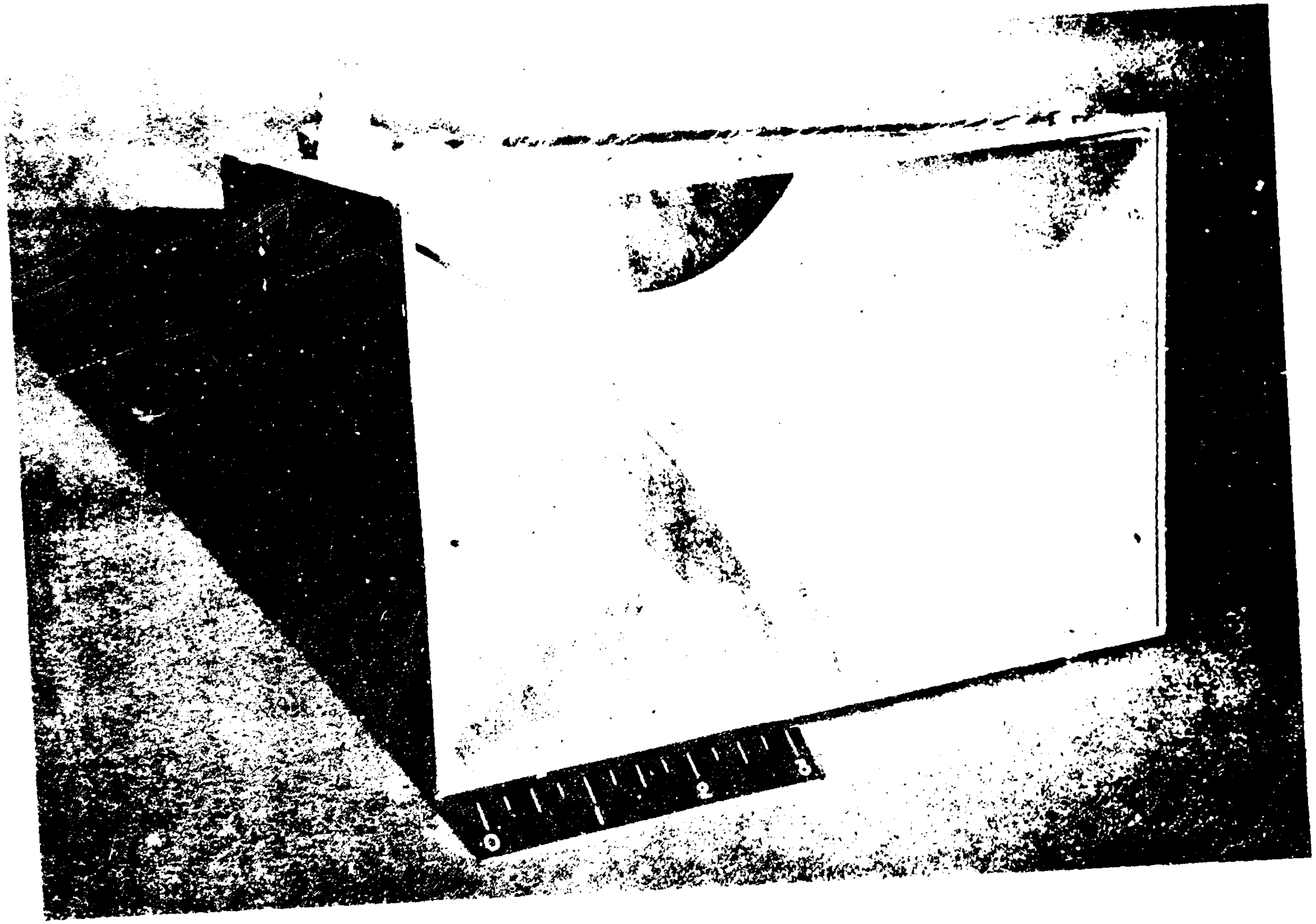
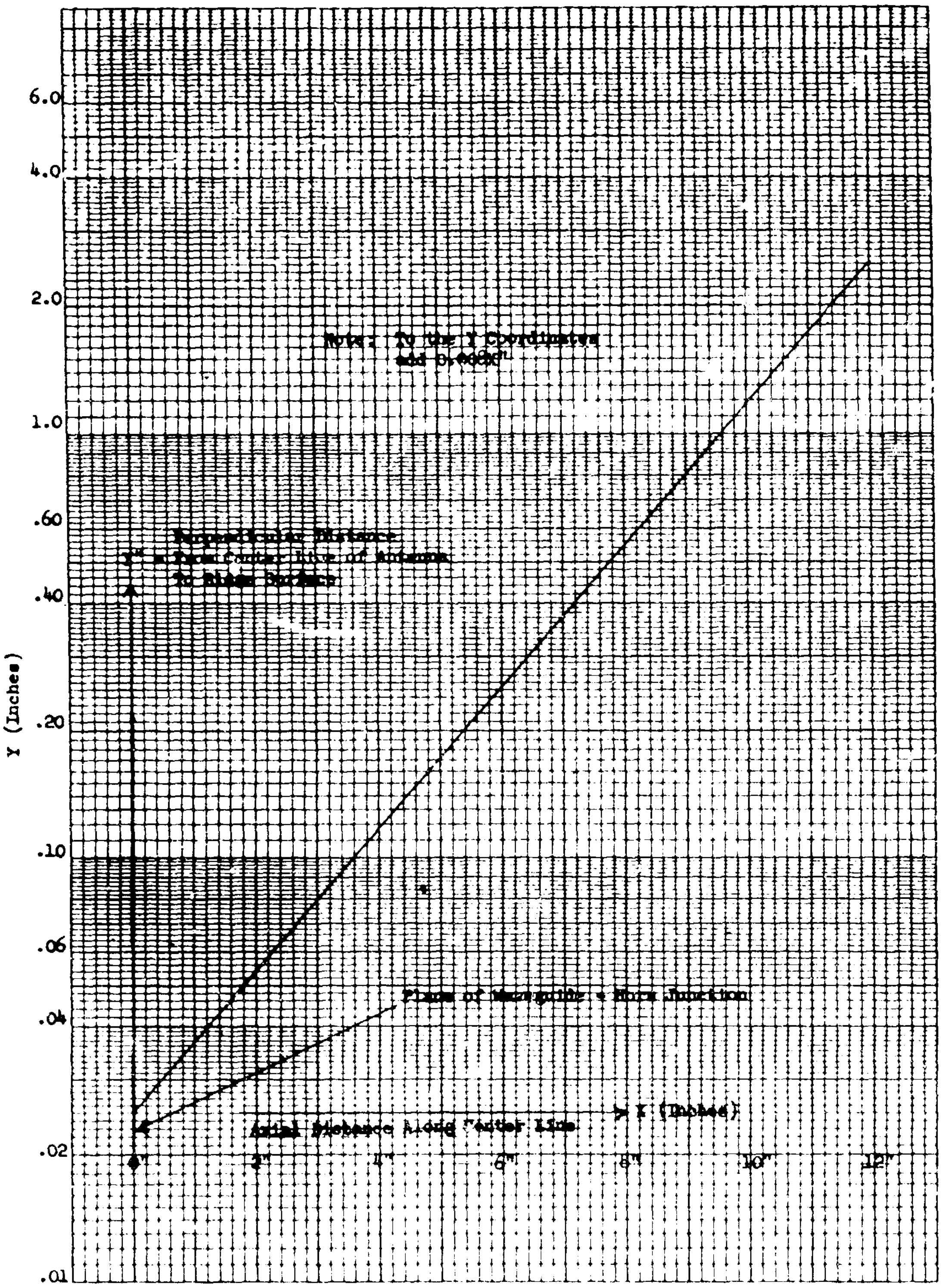


FIGURE 1 BROADBAND FEED HORN



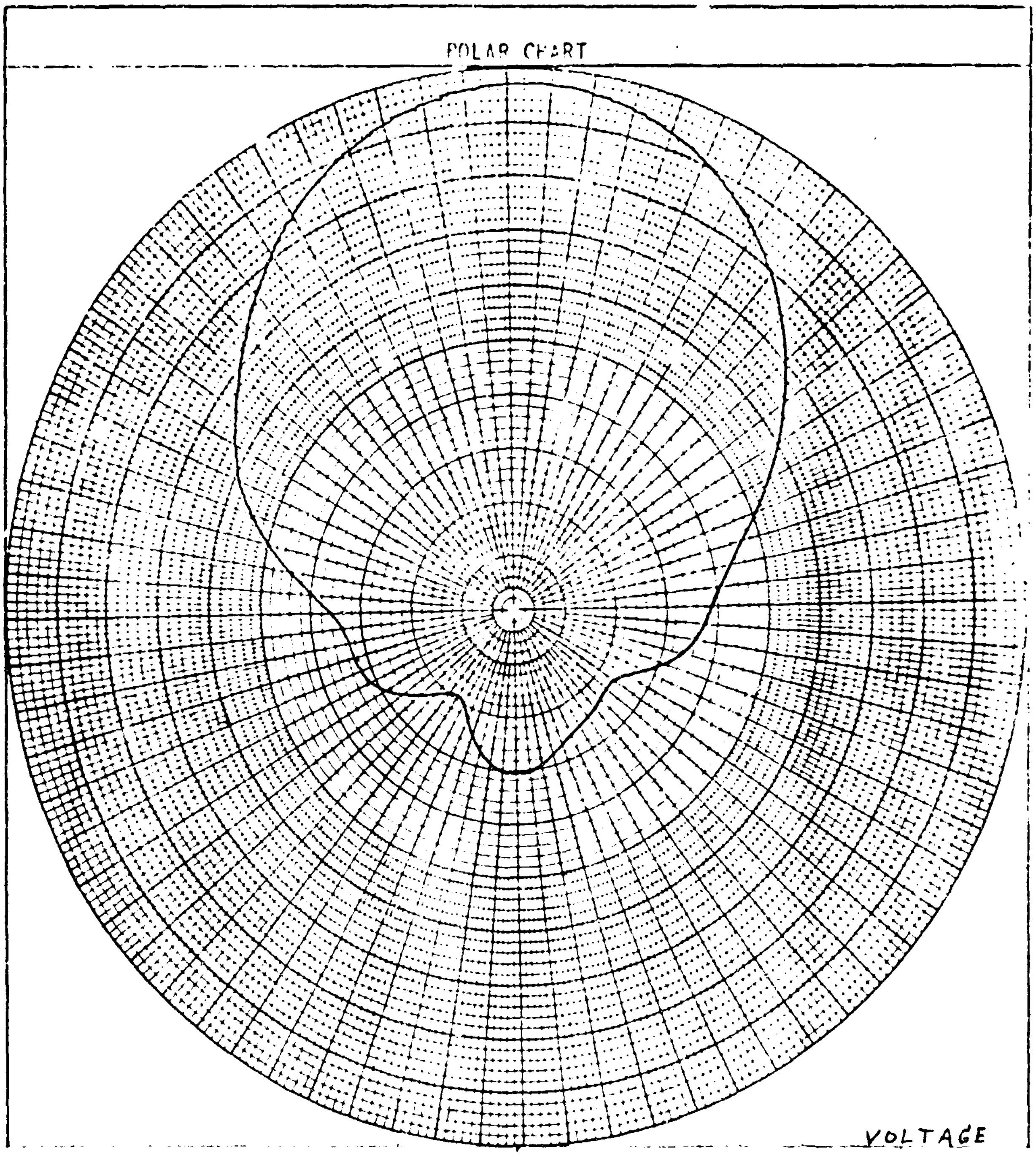
BROADBAND FEED HORN

FIGURE 2 DEVELOPMENT MODEL



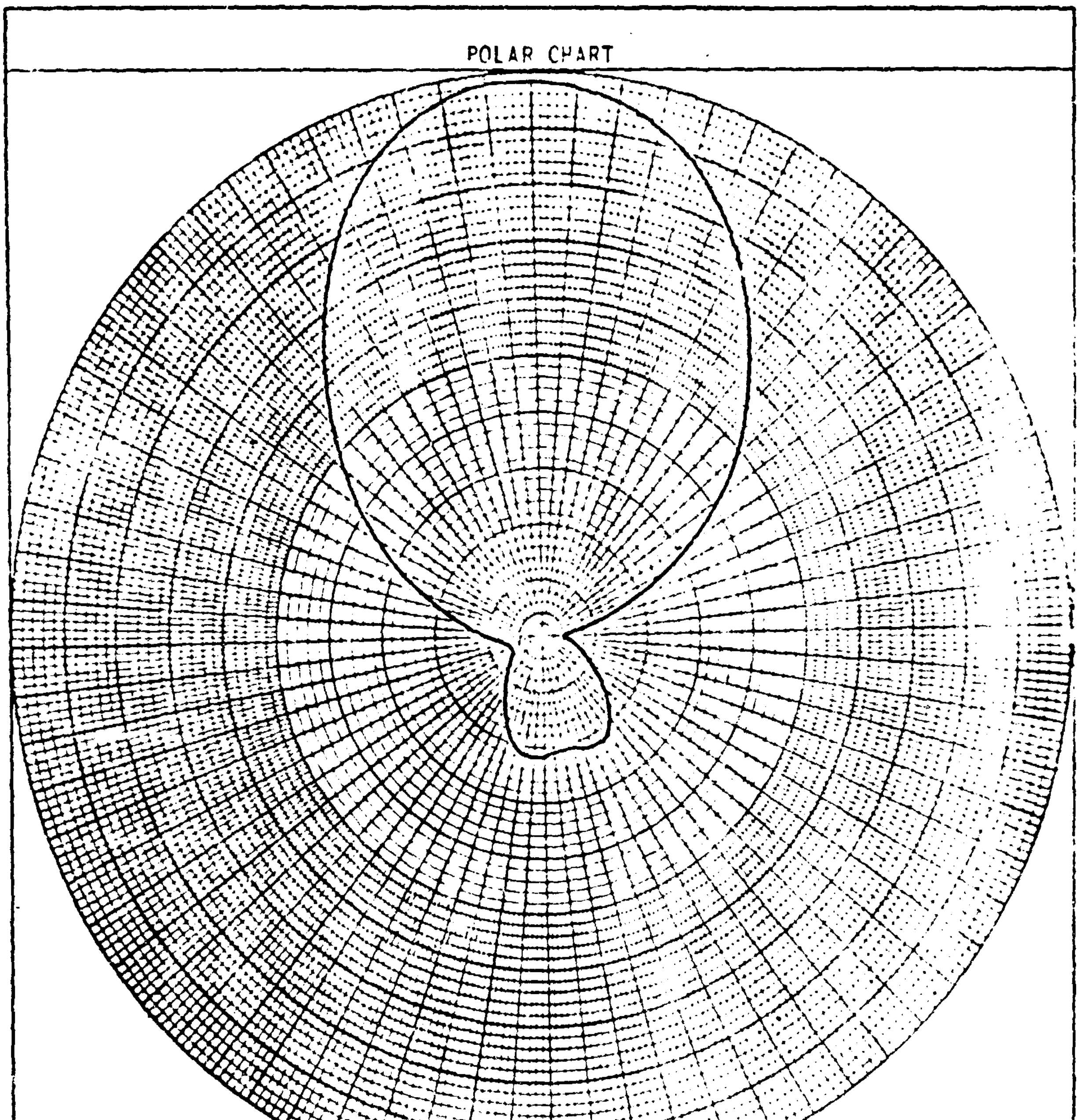
BROADBAND FEED HORN

FIGURE 3 - RIDGE CURVE COORDINATES



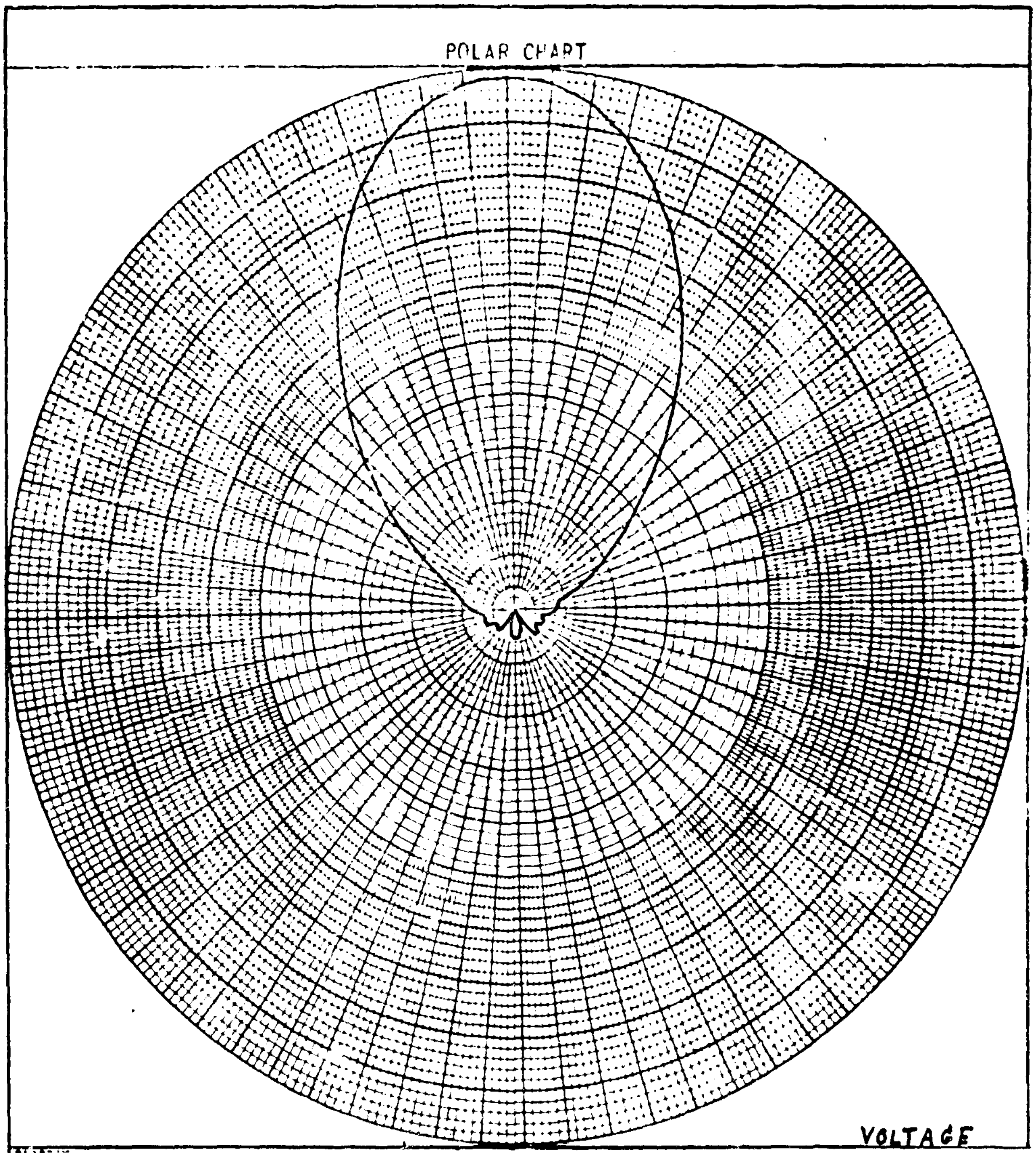
BROADBAND FEED HORN

FIGURE 4 1.0 GHz E-PLANE



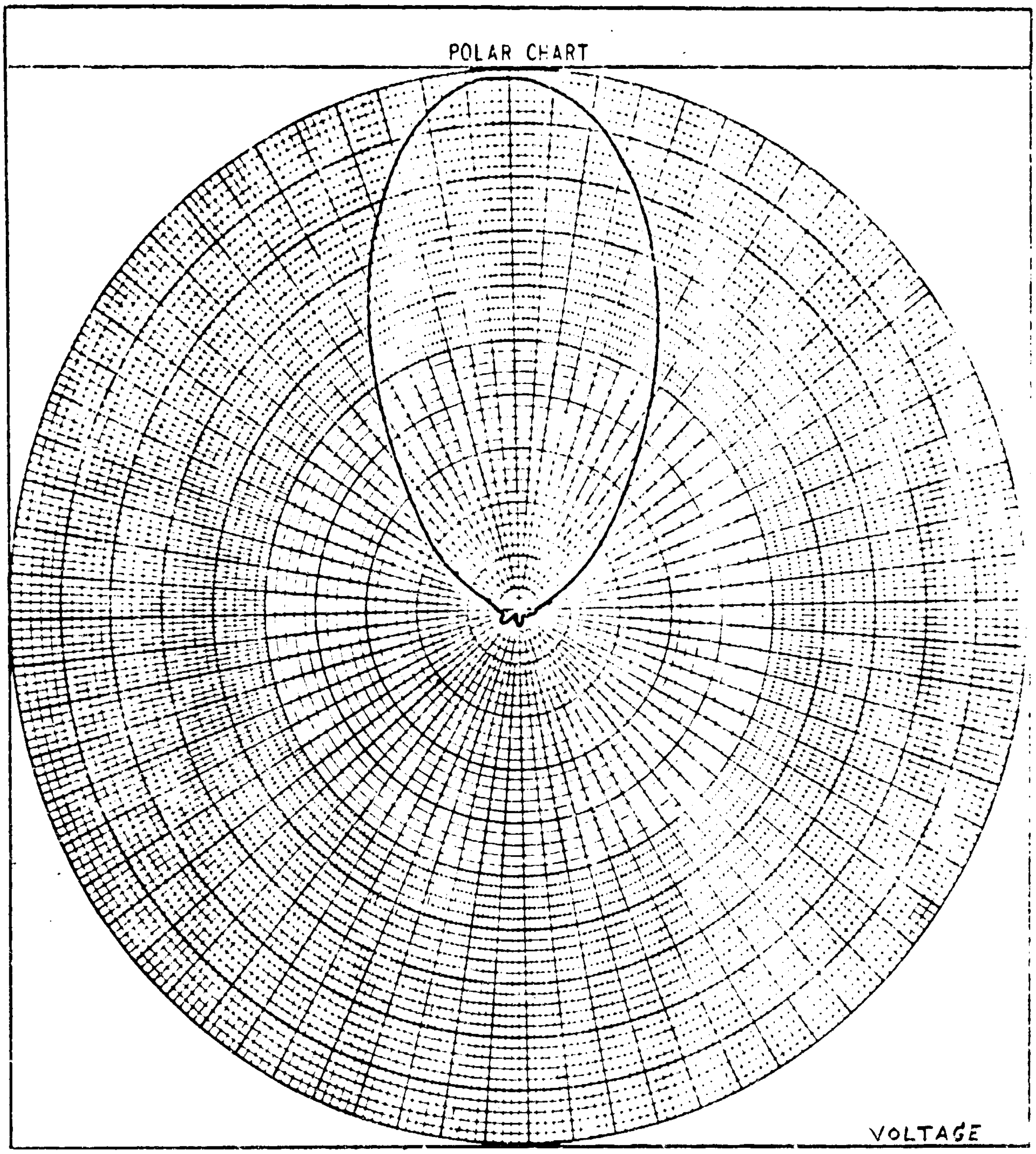
BROADBAND FEED HORN

FIGURE 5 1.0 GHz H-PLANE



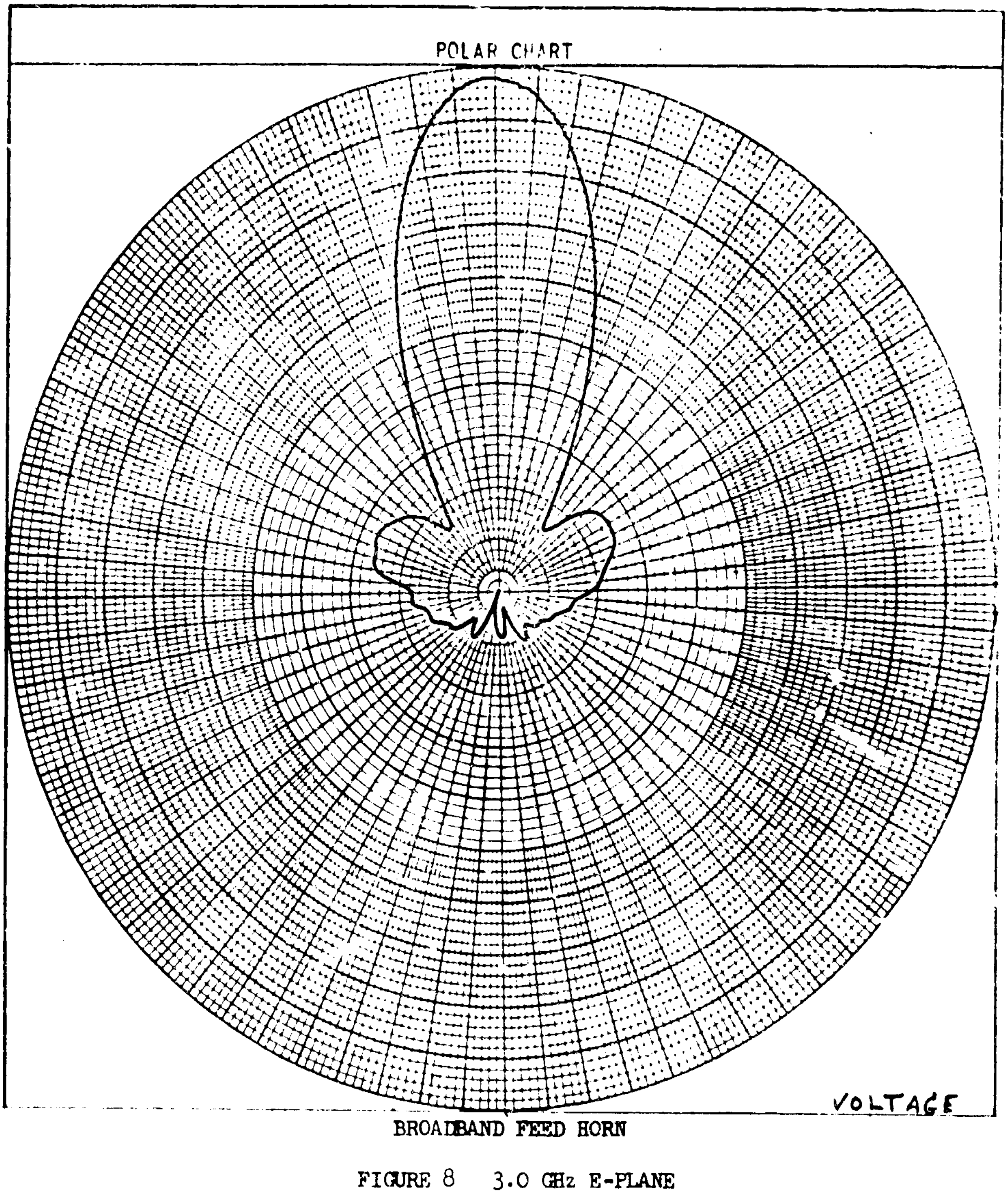
BROADBAND FEED HORN

FIGURE 6 2.0 GHz E-PLANE



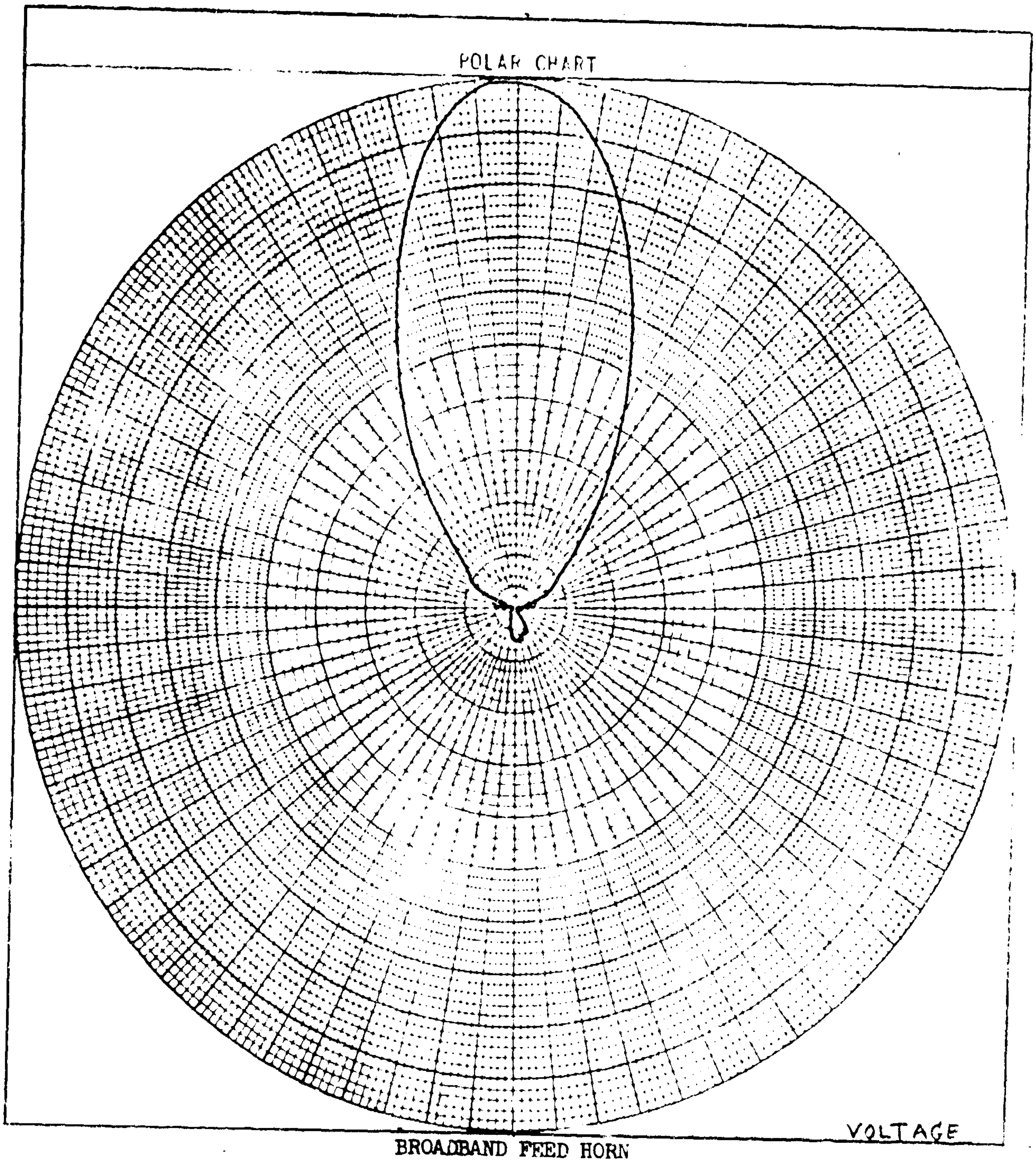
BROADBAND FEED HORN

FIGURE 7 2.0 GHz H-PLANE



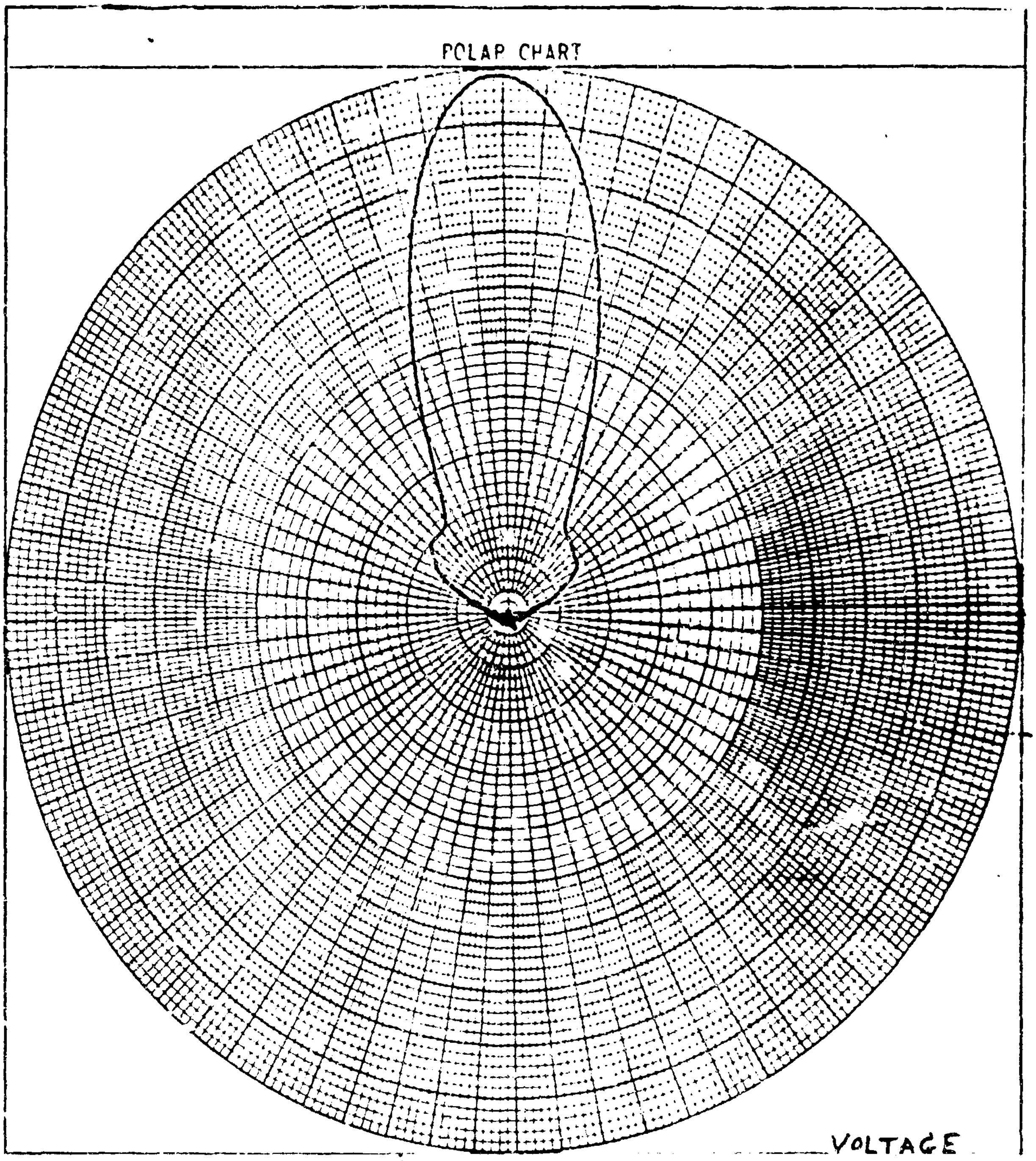
BROADBAND FEED HORN

FIGURE 8 3.0 GHz E-PLANE



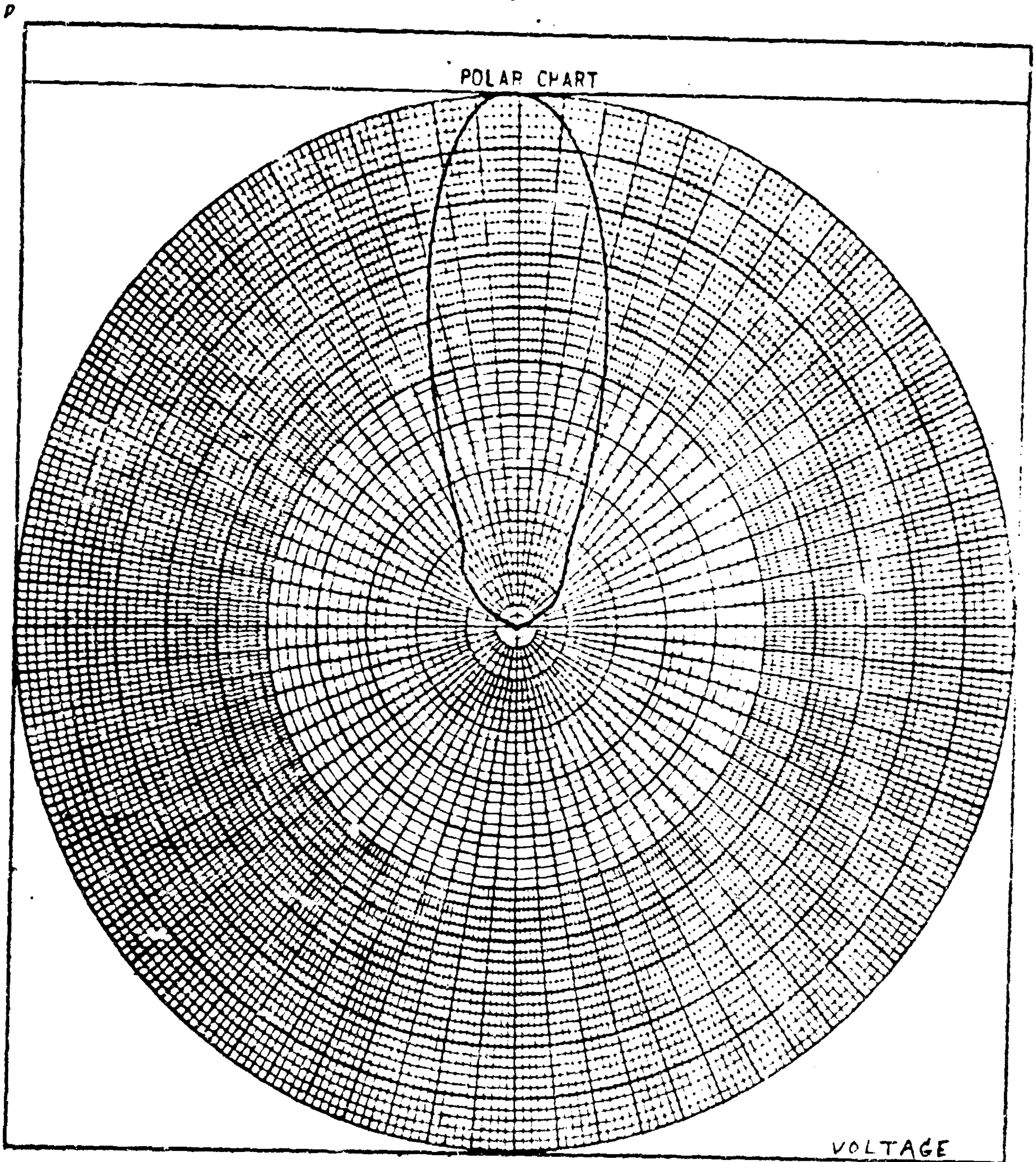
BROADBAND FEED HORN

FIGURE 9 3.0 GHz H-PLANE



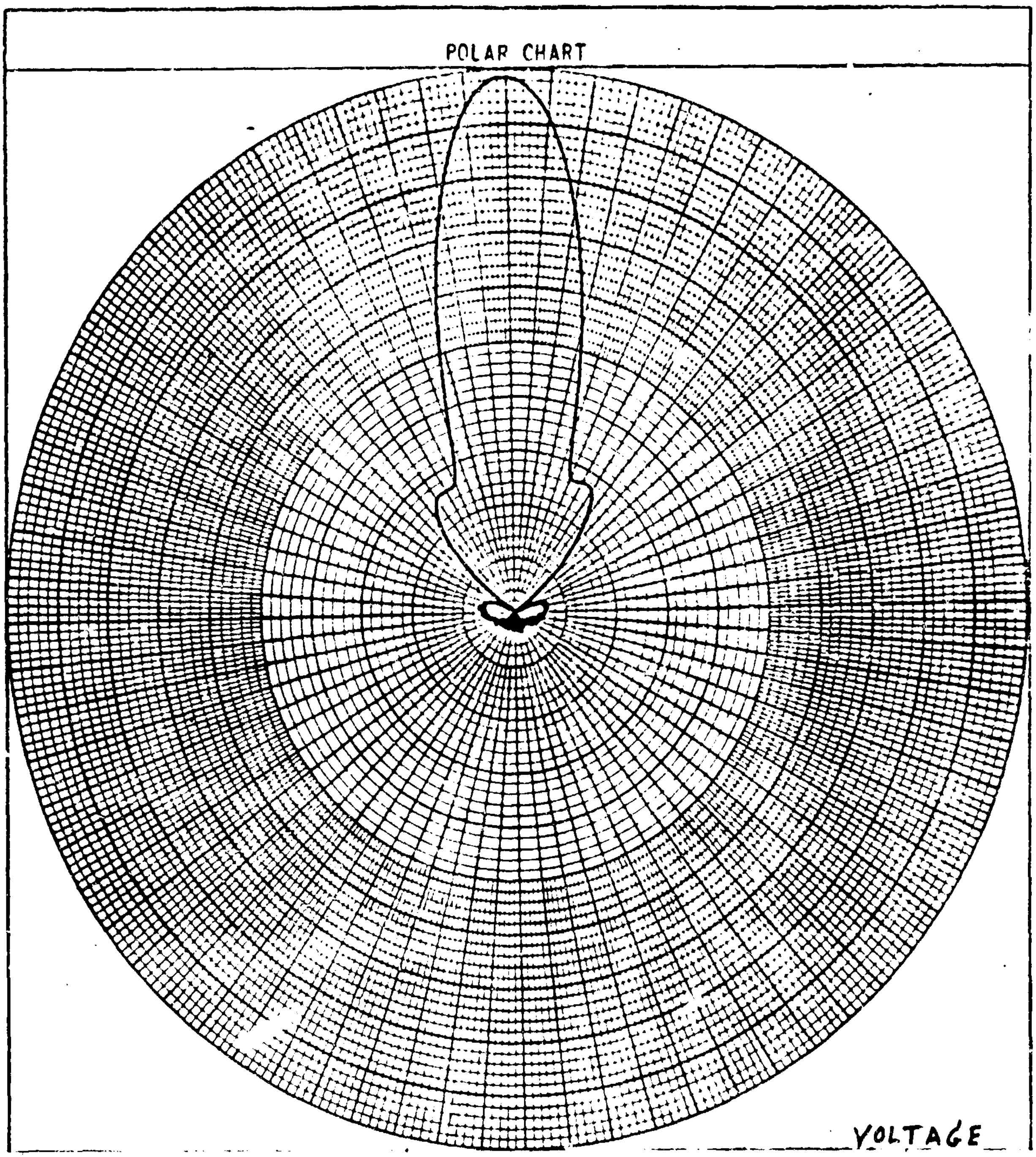
BROADBAND FEED HORN

FIGURE 10 4.0 GHz E-PLANE



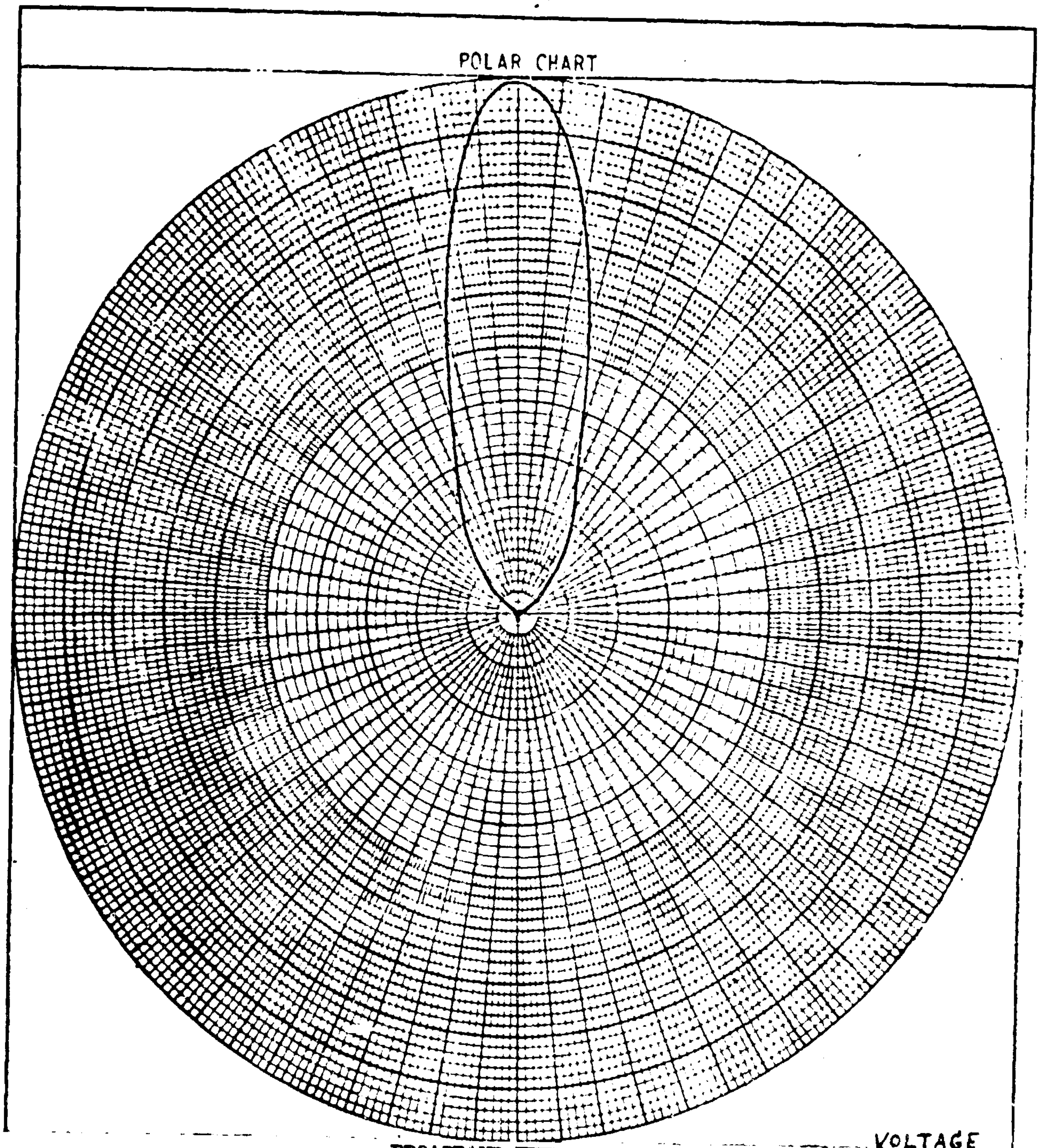
BROADBAND FEED HORN

FIGURE 11 4.0 GHz H-PLANE



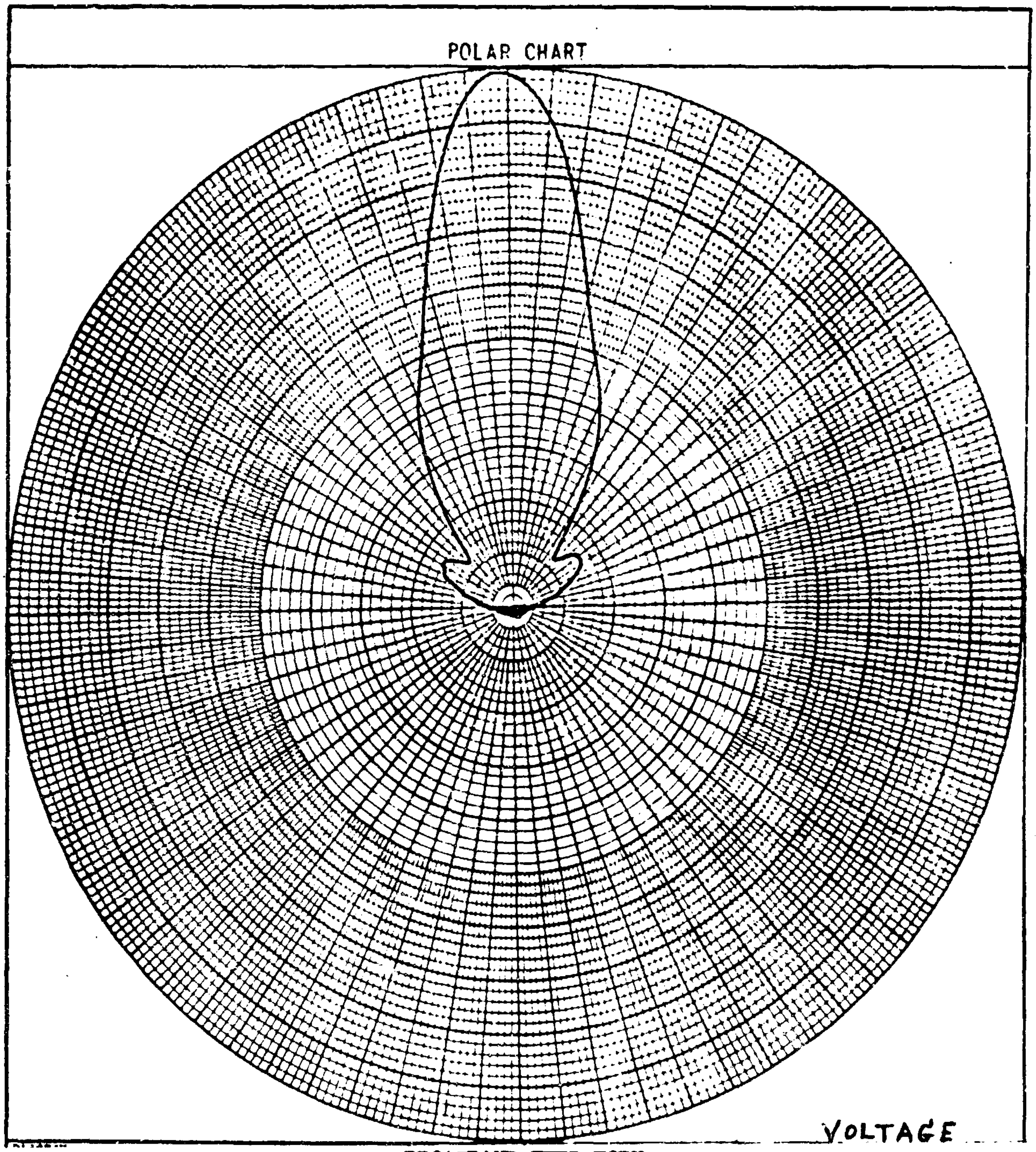
BROADBAND FEED HORN

FIGURE 12 5.0 GHz E-PLANE



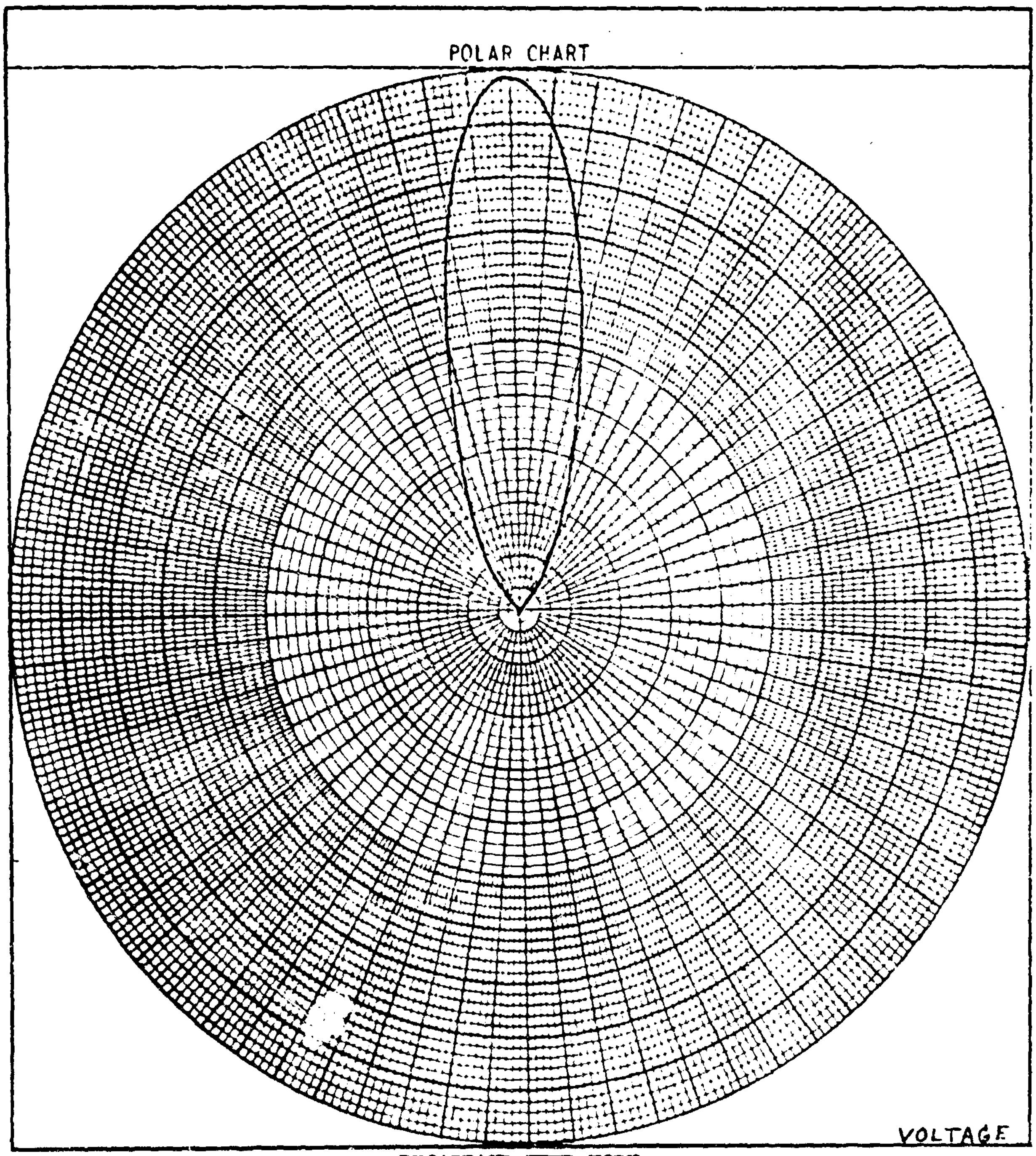
BROADBAND FEED HORN

FIGURE 13 5.0 GHz H-PLANE



BROADBAND FEED HORN

FIGURE 14 6.0 GHz E-PLANE



BROADBAND FEED HORN

FIGURE 15 6.0 GHz H-PLANE

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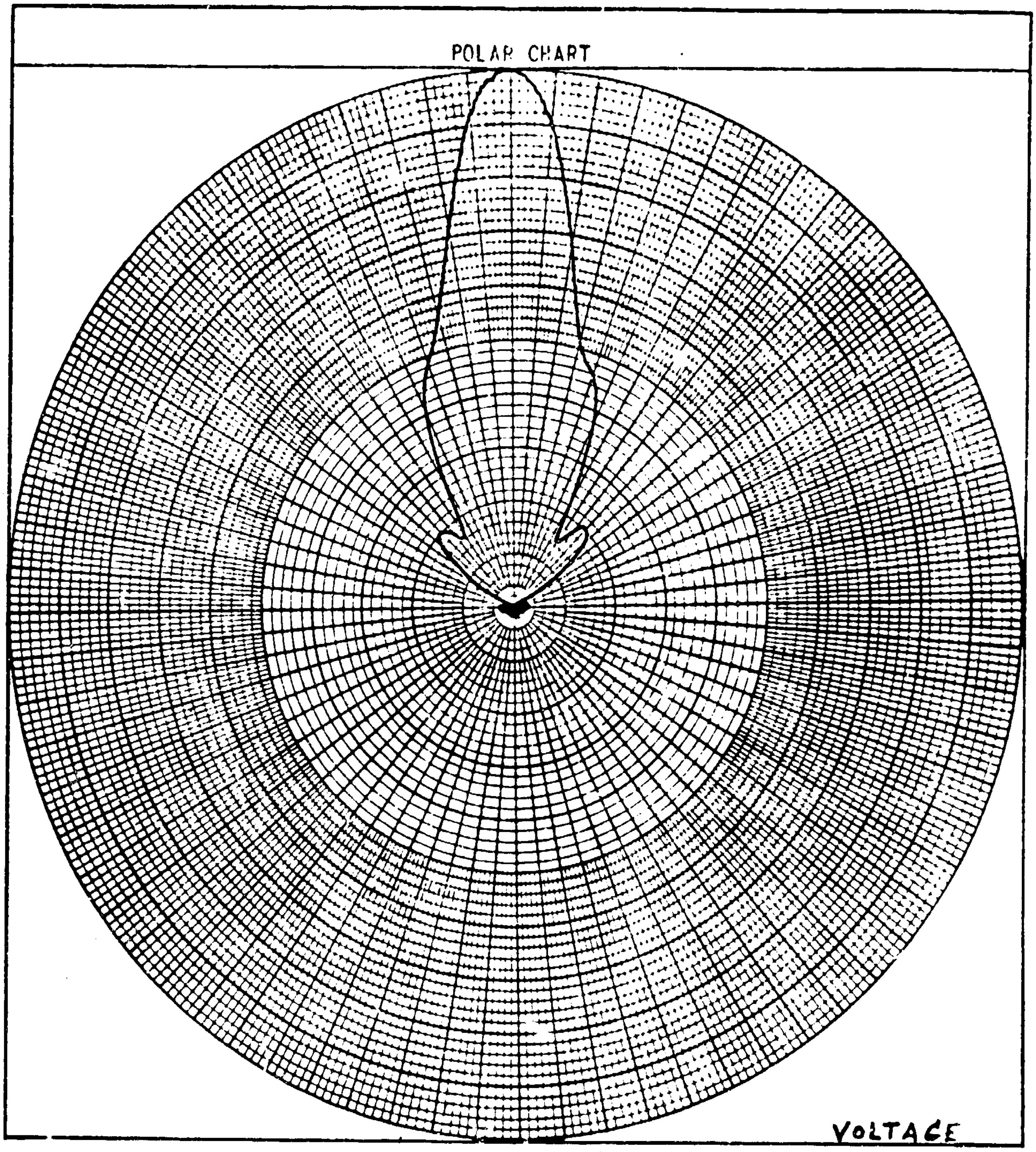
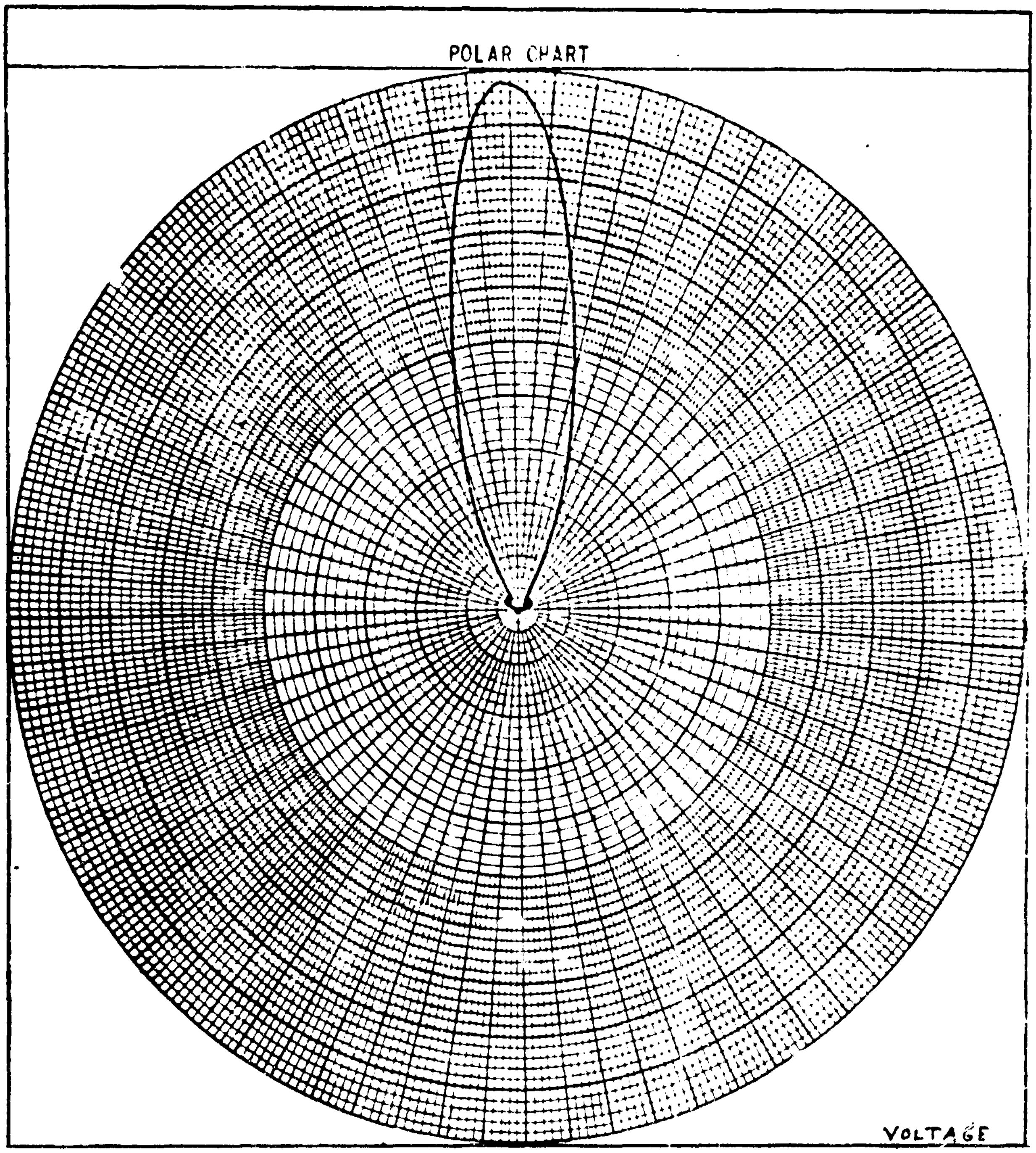


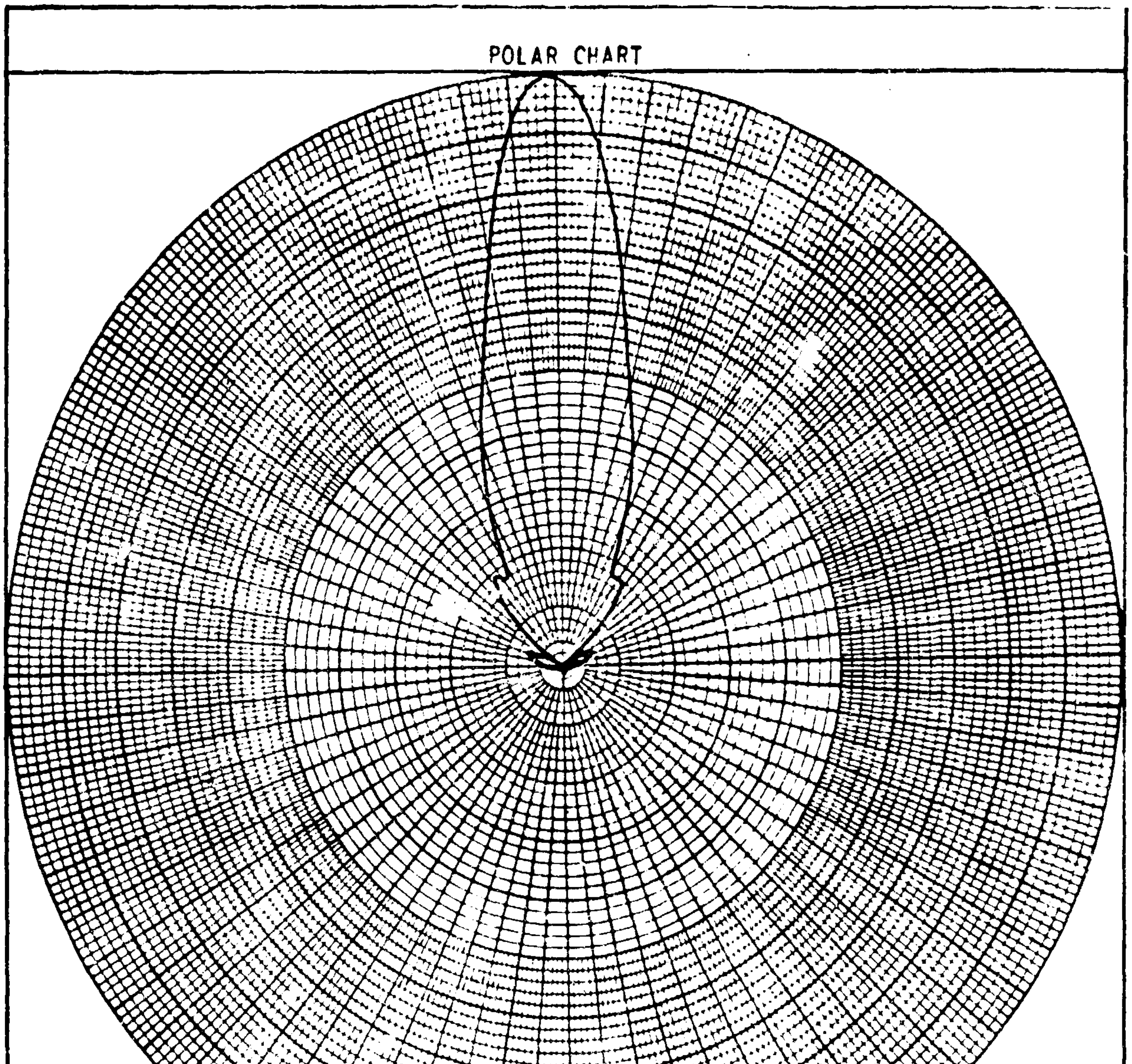
BROADBAND FEED HORN

FIGURE 16   7.0 GHz E-PLANE



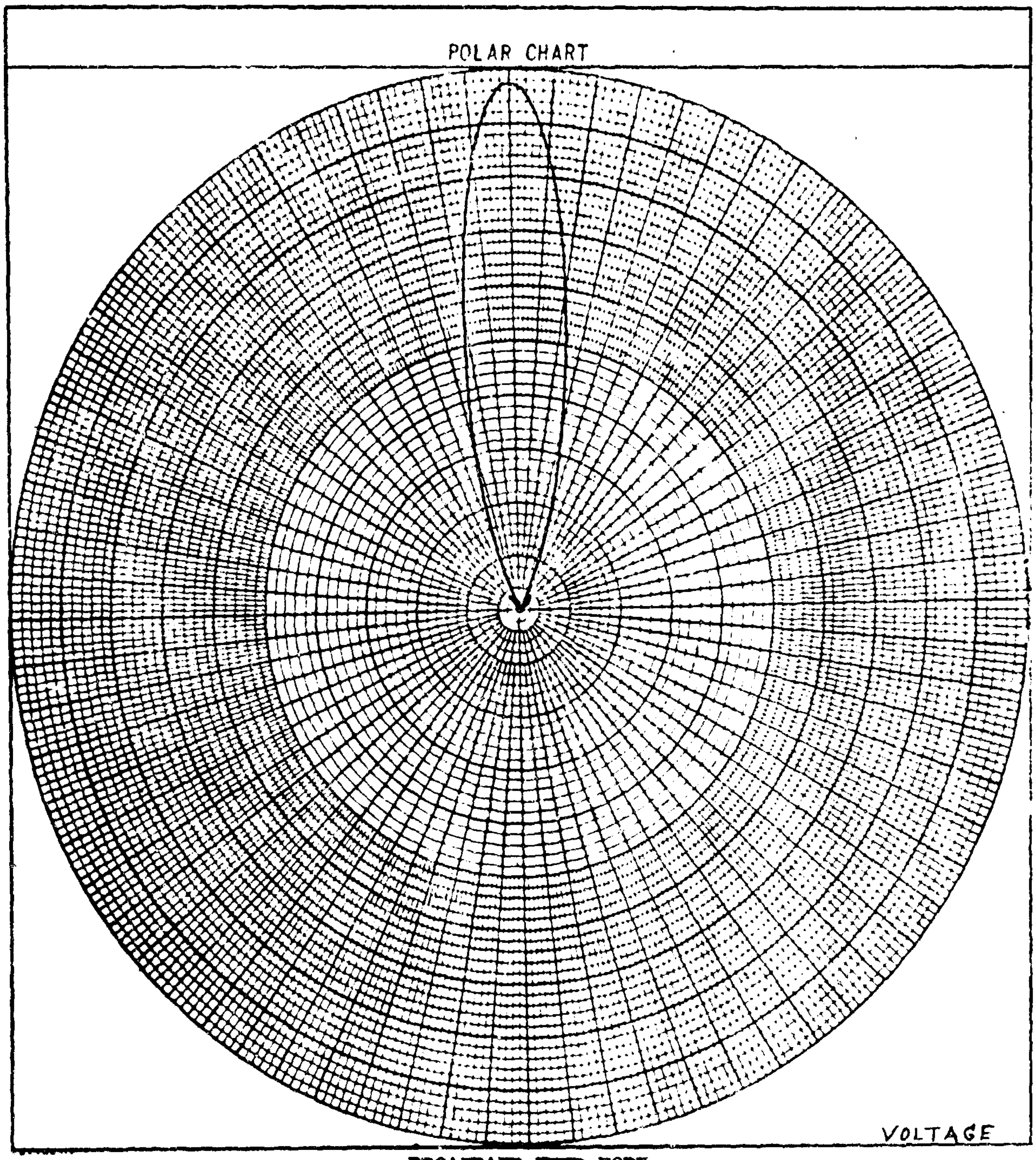
BROADBAND FEED HORN

FIGURE 17 7.0 GHz H-PLANE



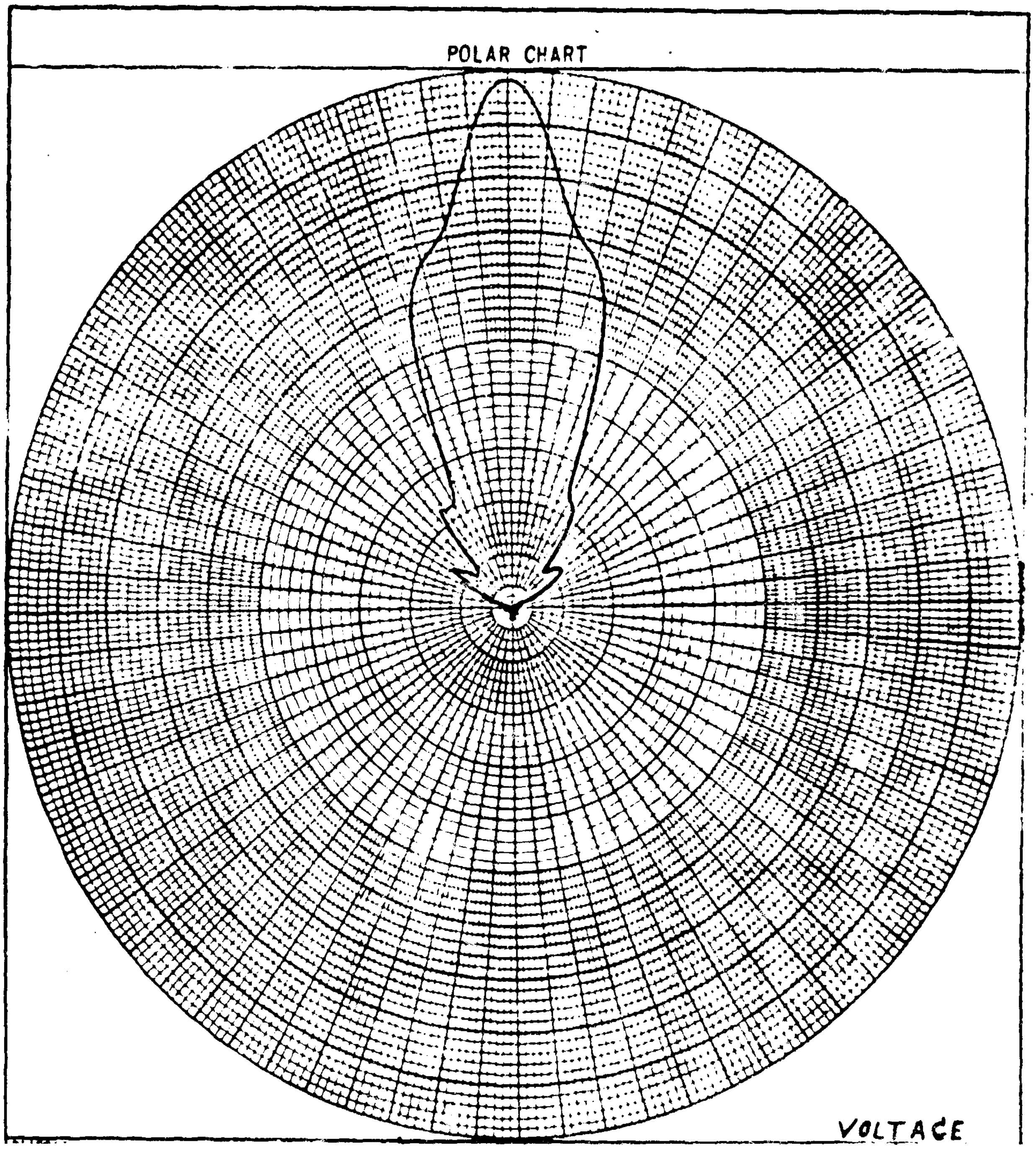
BROADBAND FEED HORN

FIGURE 18 8.0 GHz E-PLANE



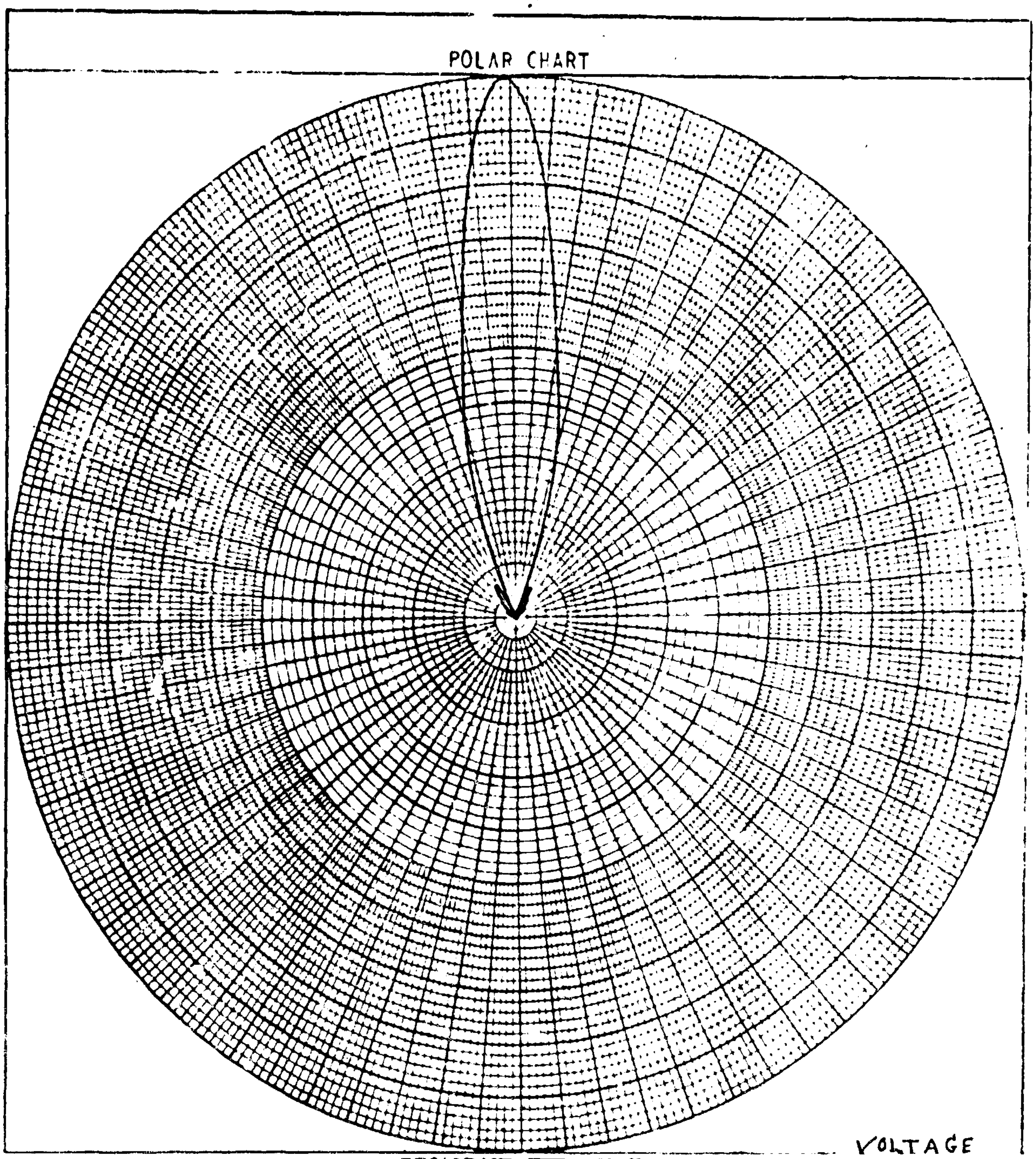
BROADBAND FEED HORN

FIGURE 19 8.0 GHz H-PLANE



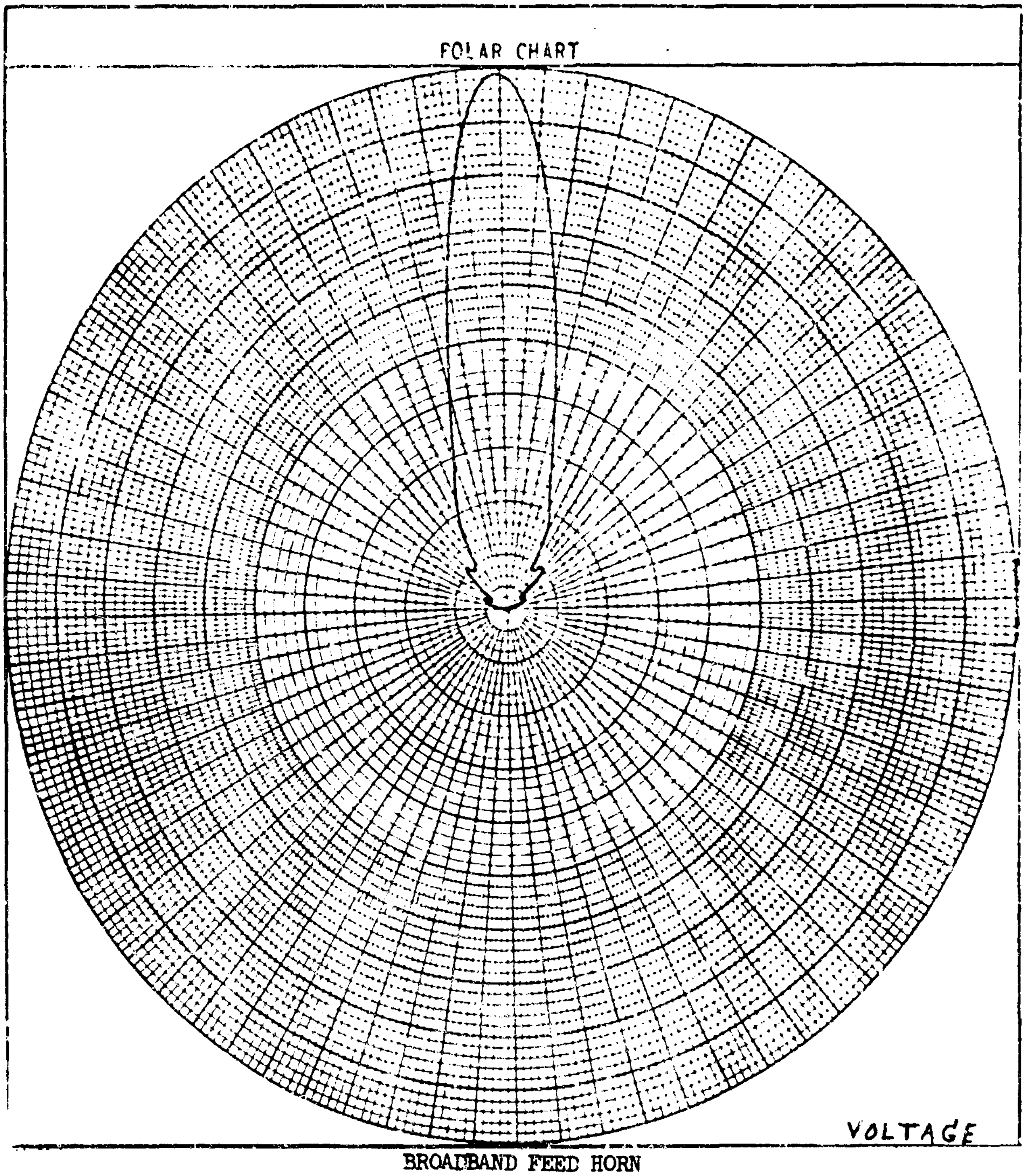
BROADBAND FEED HORN

FIGURE 20   9.0 GHz E-PLANE



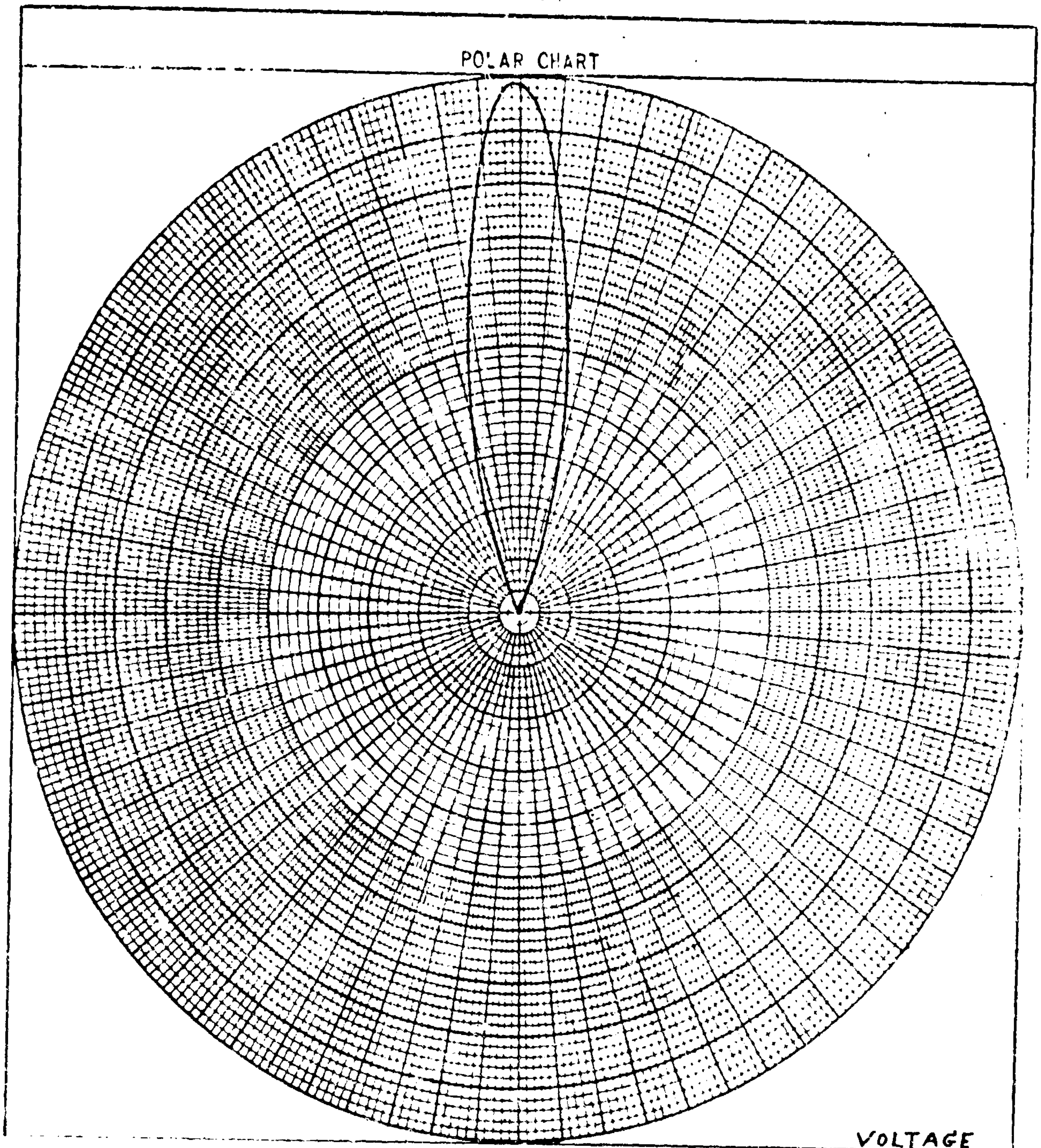
BROADBAND FEED HORN

FIGURE 21   9.0 GHz H-PLANE



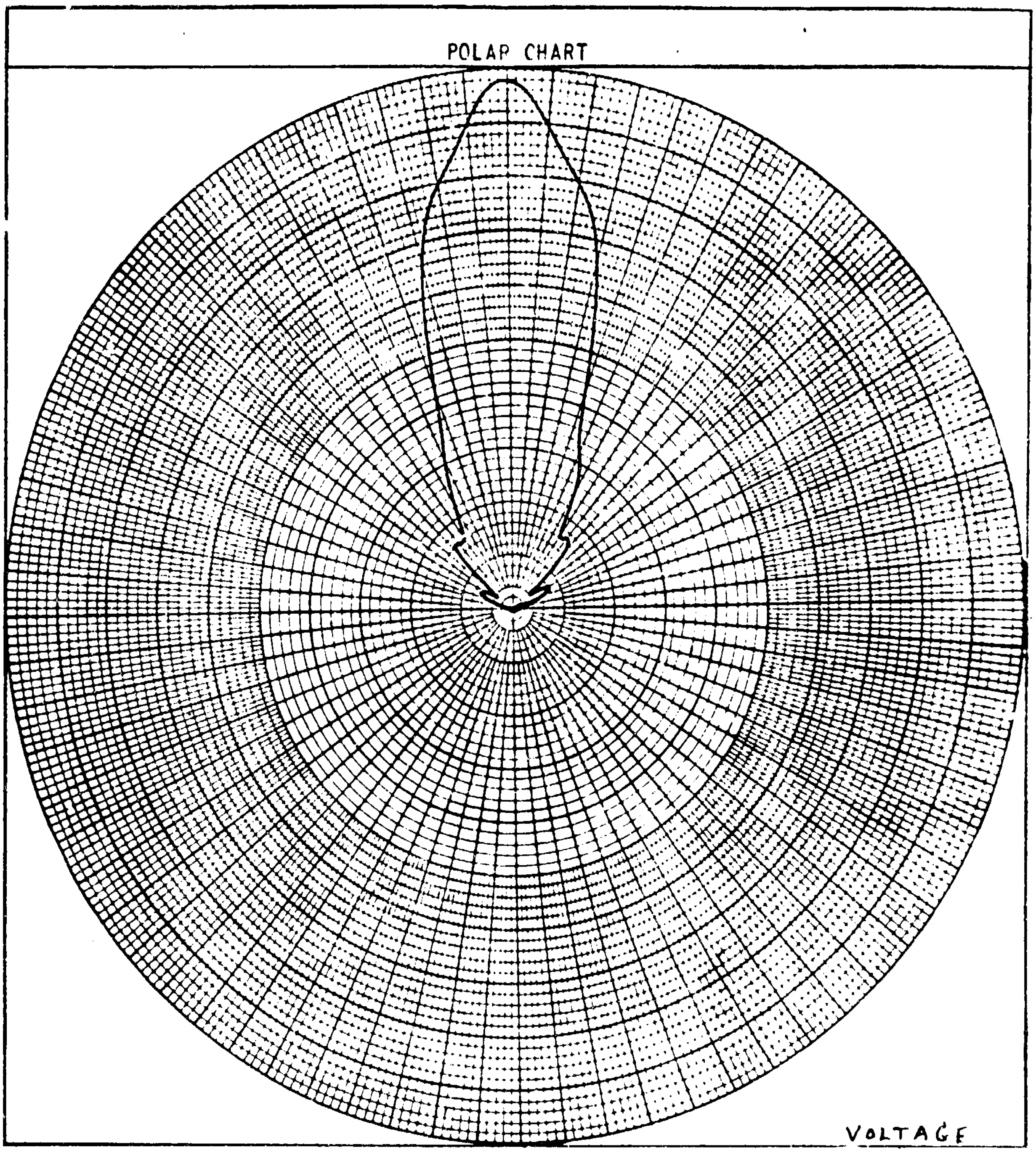
BROADBAND FEED HORN

FIGURE 22 10.0 GHz E-PLANE



BROADBAND FEED HORN

FIGURE 23 10.0 GHz H-PLANE



BROADBAND FEED HORN

FIGURE 24 11.0 GHz E-PLANE

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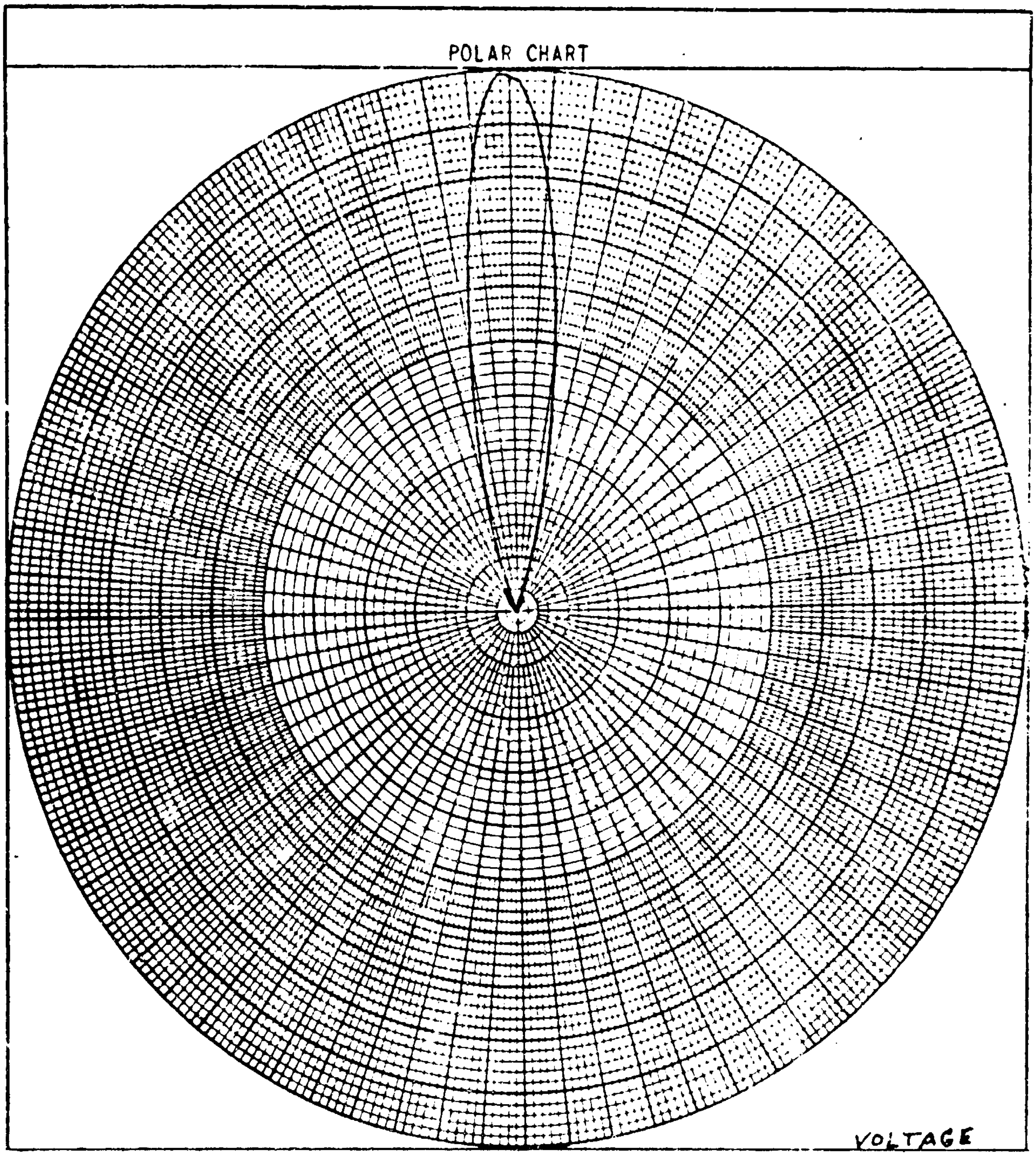
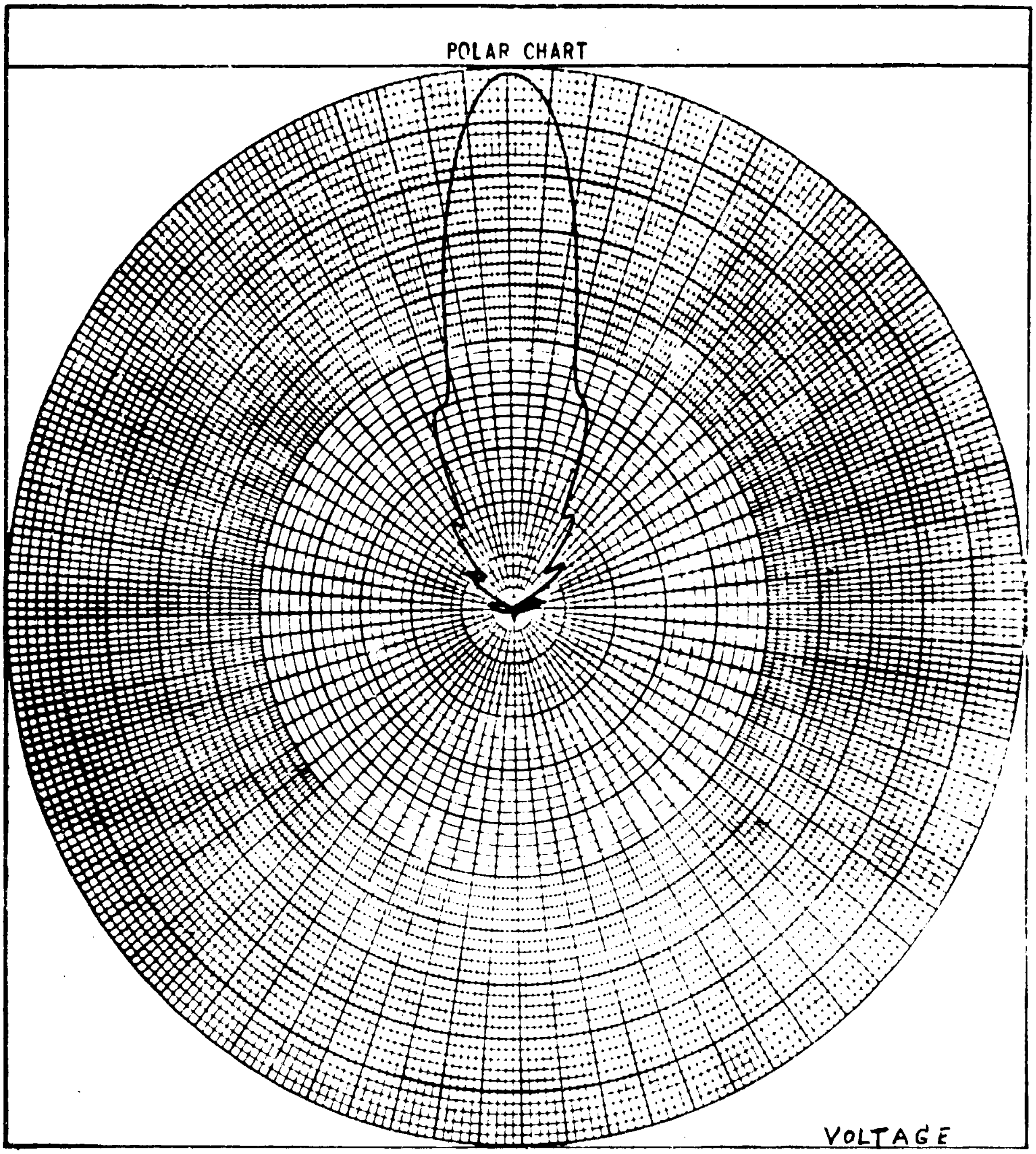


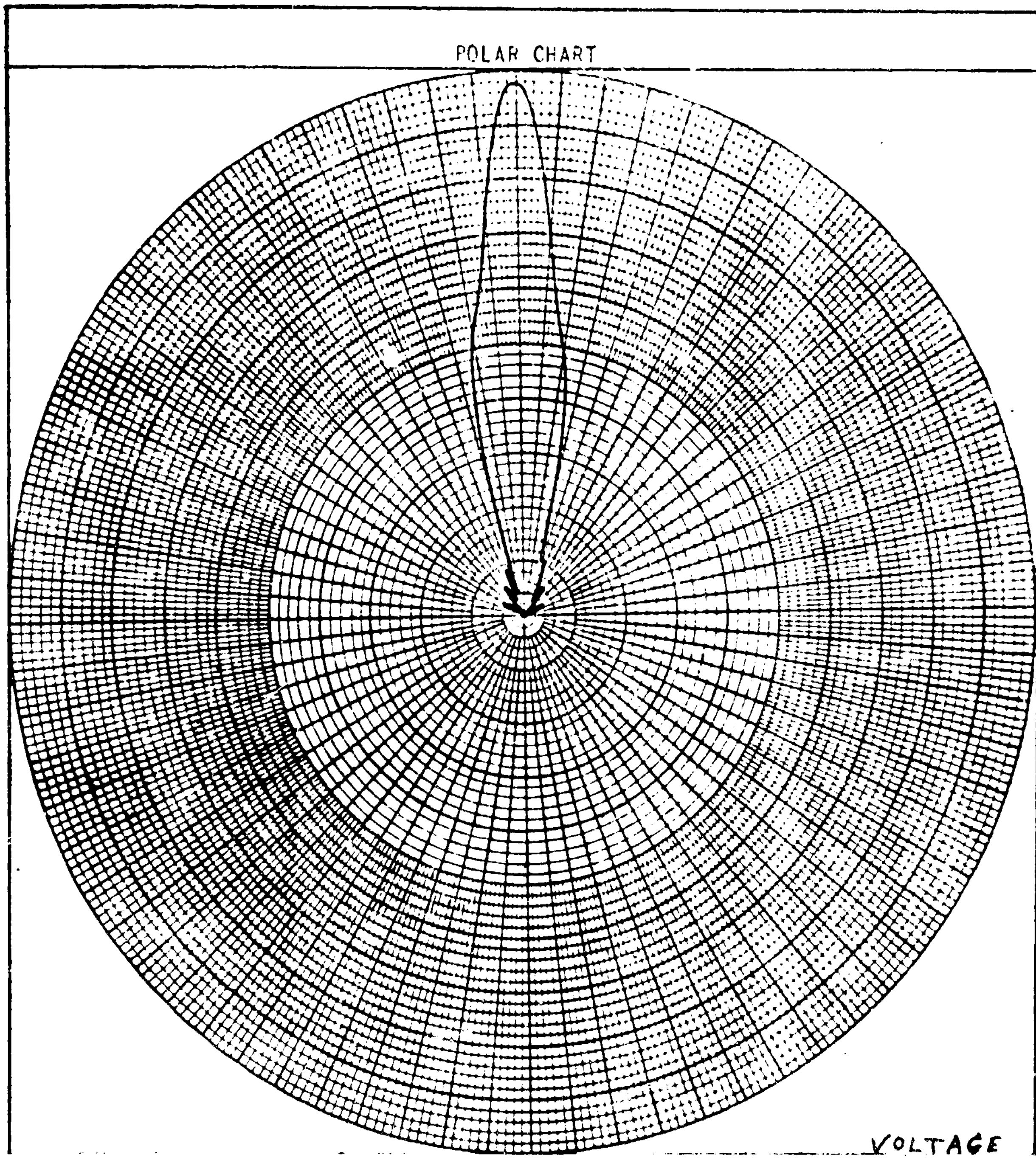
BROADBAND FEED HORN

FIGURE 25 11.0 GHz H-PLANE



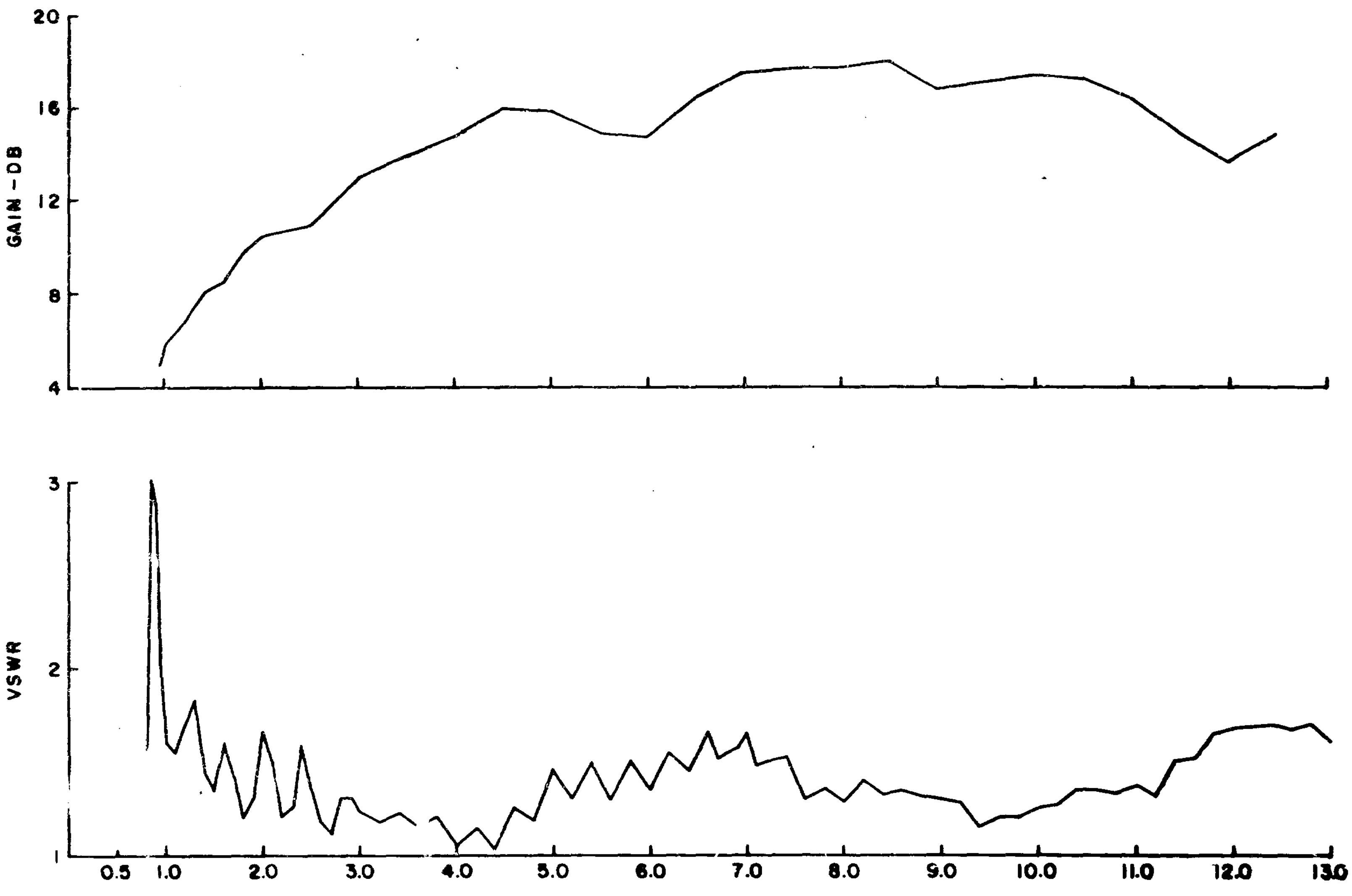
BROADBAND FEED HORN

FIGURE 26 12.0 GHz E-PLANE



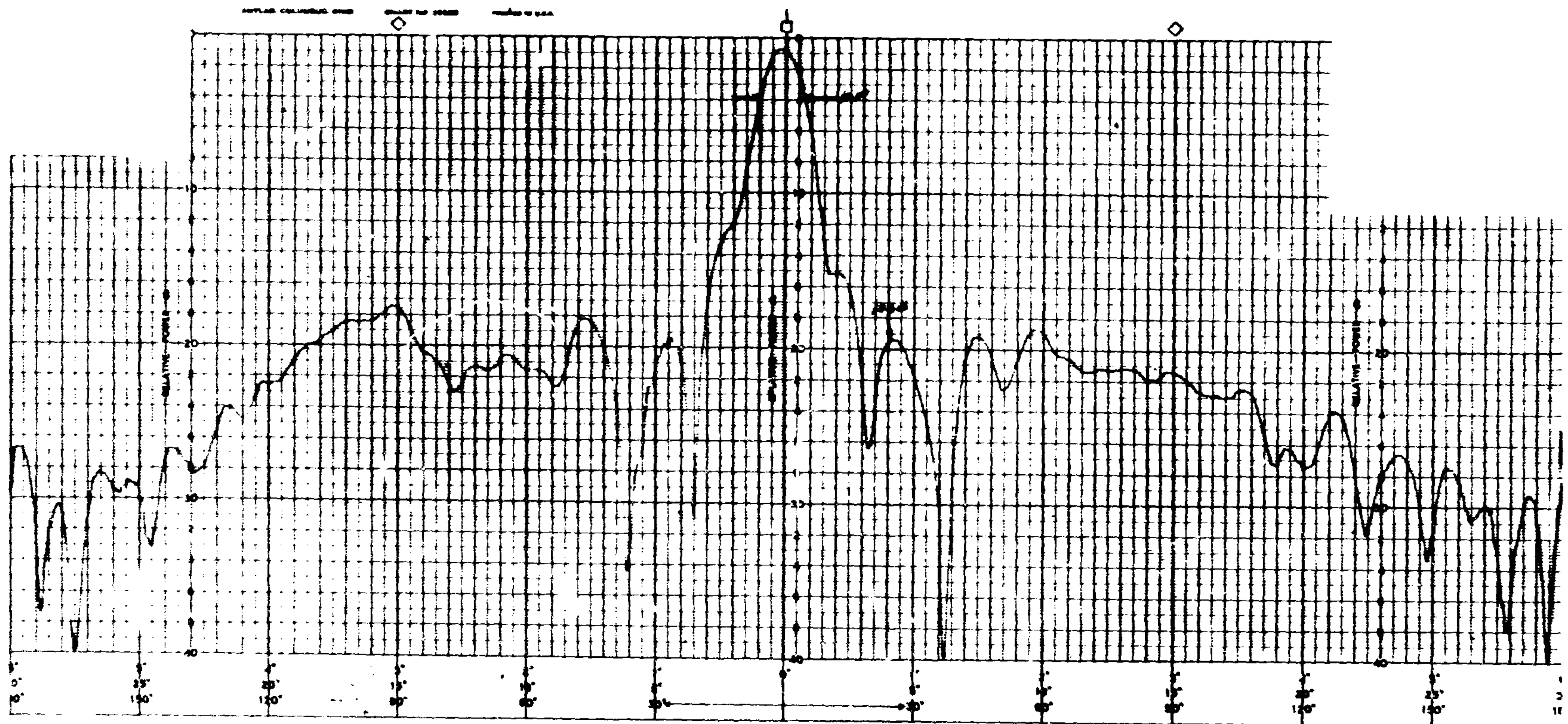
BROADBAND FEED HORN

FIGURE 27 12.0 GHz H-PLANE



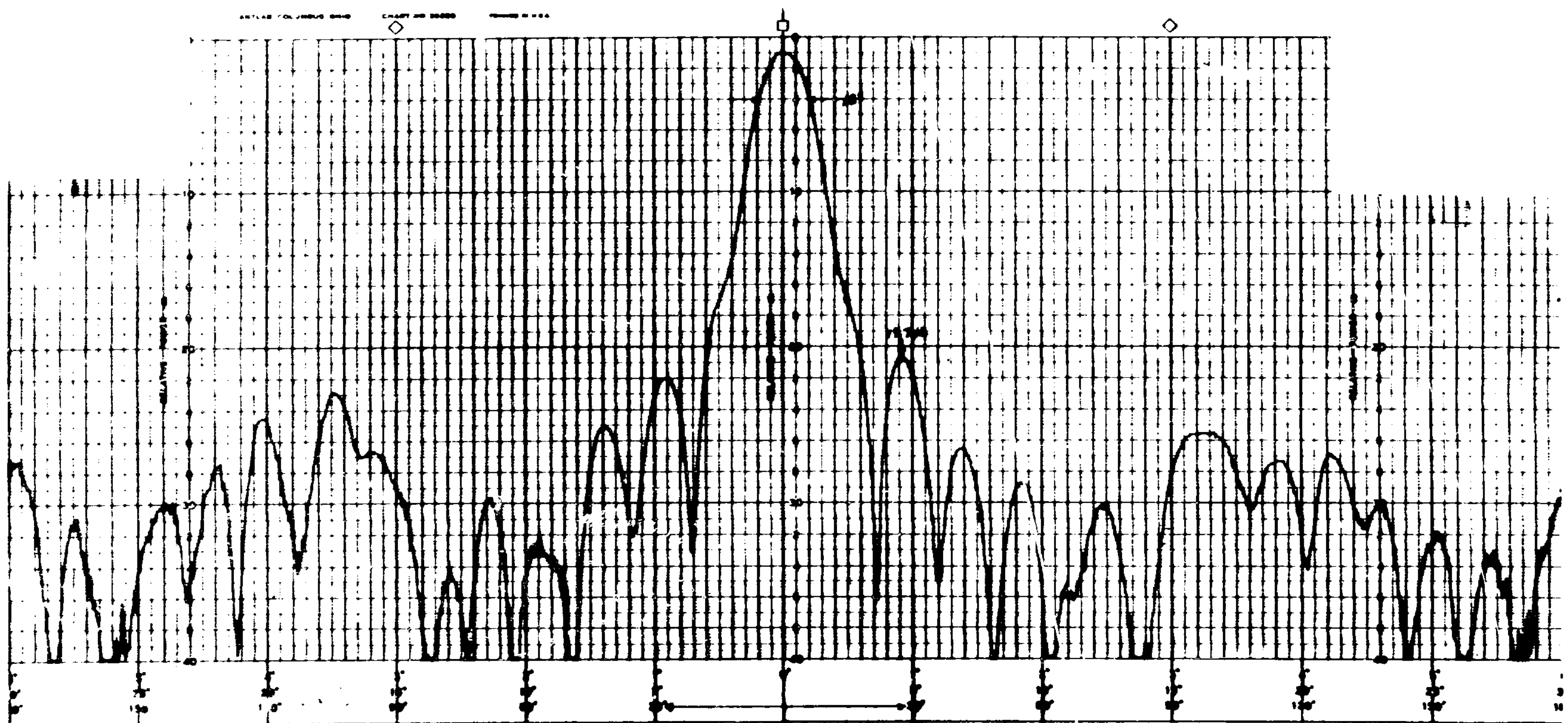
FREQUENCY IN GHz
BROADBAND FEED HORN

FIGURE 28 VSWR & GAIN



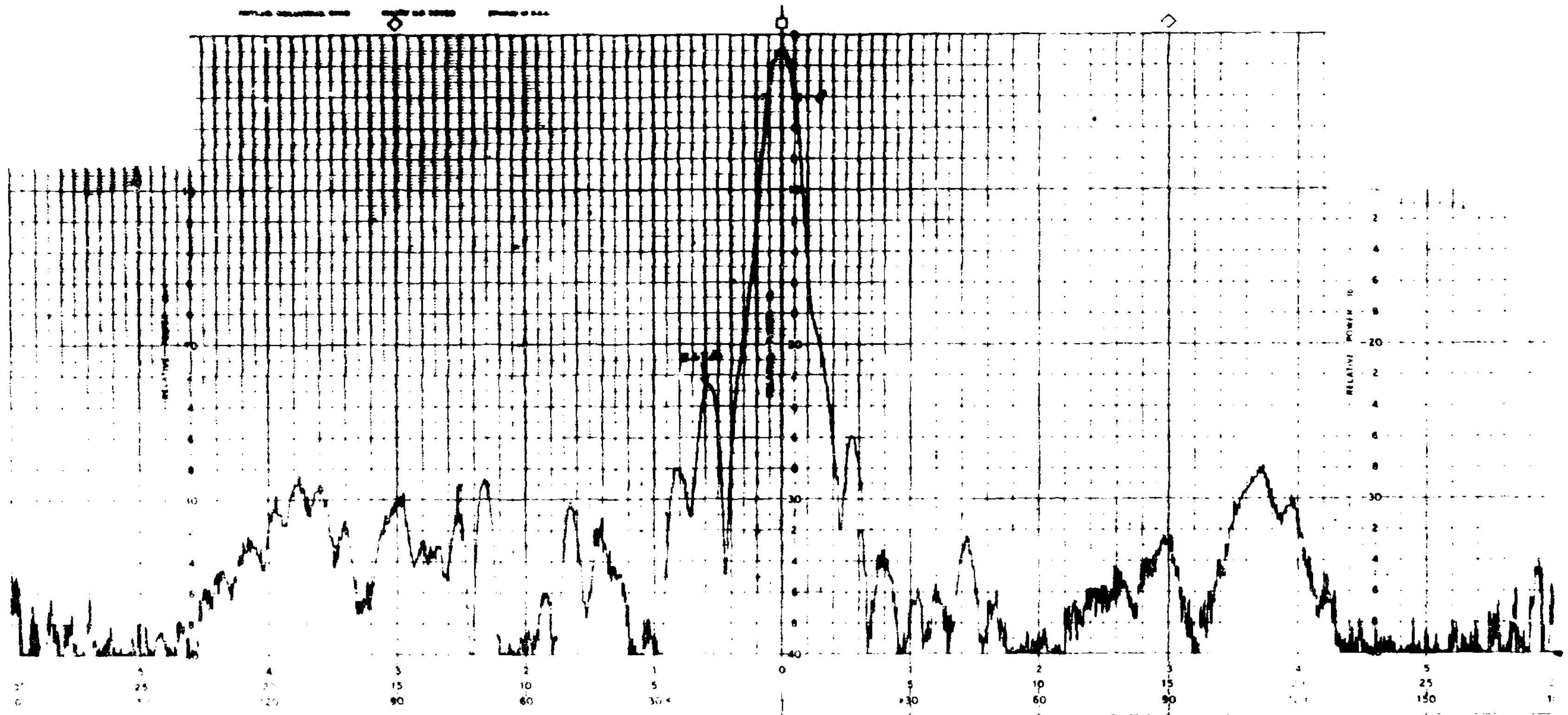
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 29 1.0 GHz E-PLANE



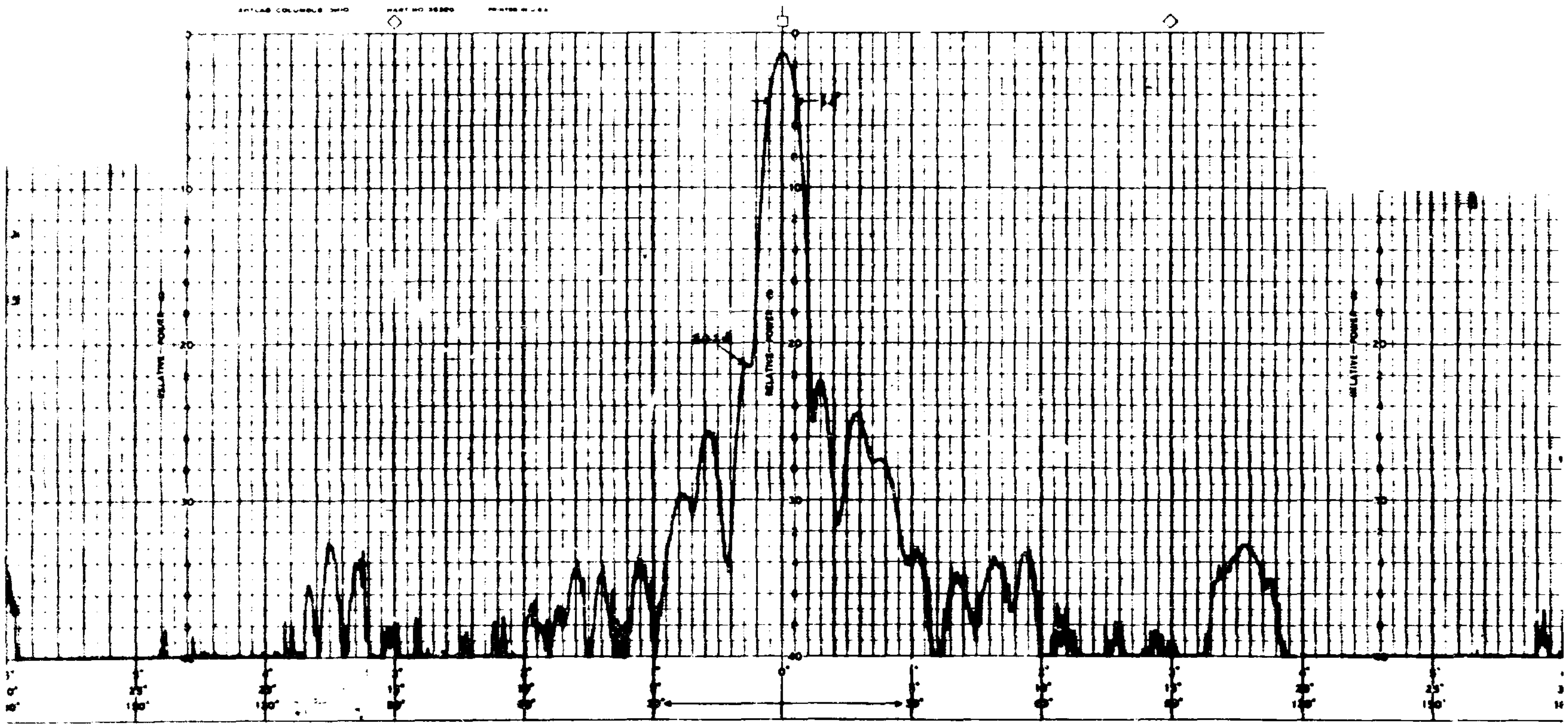
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 30 1.0 GHz H-PLANE



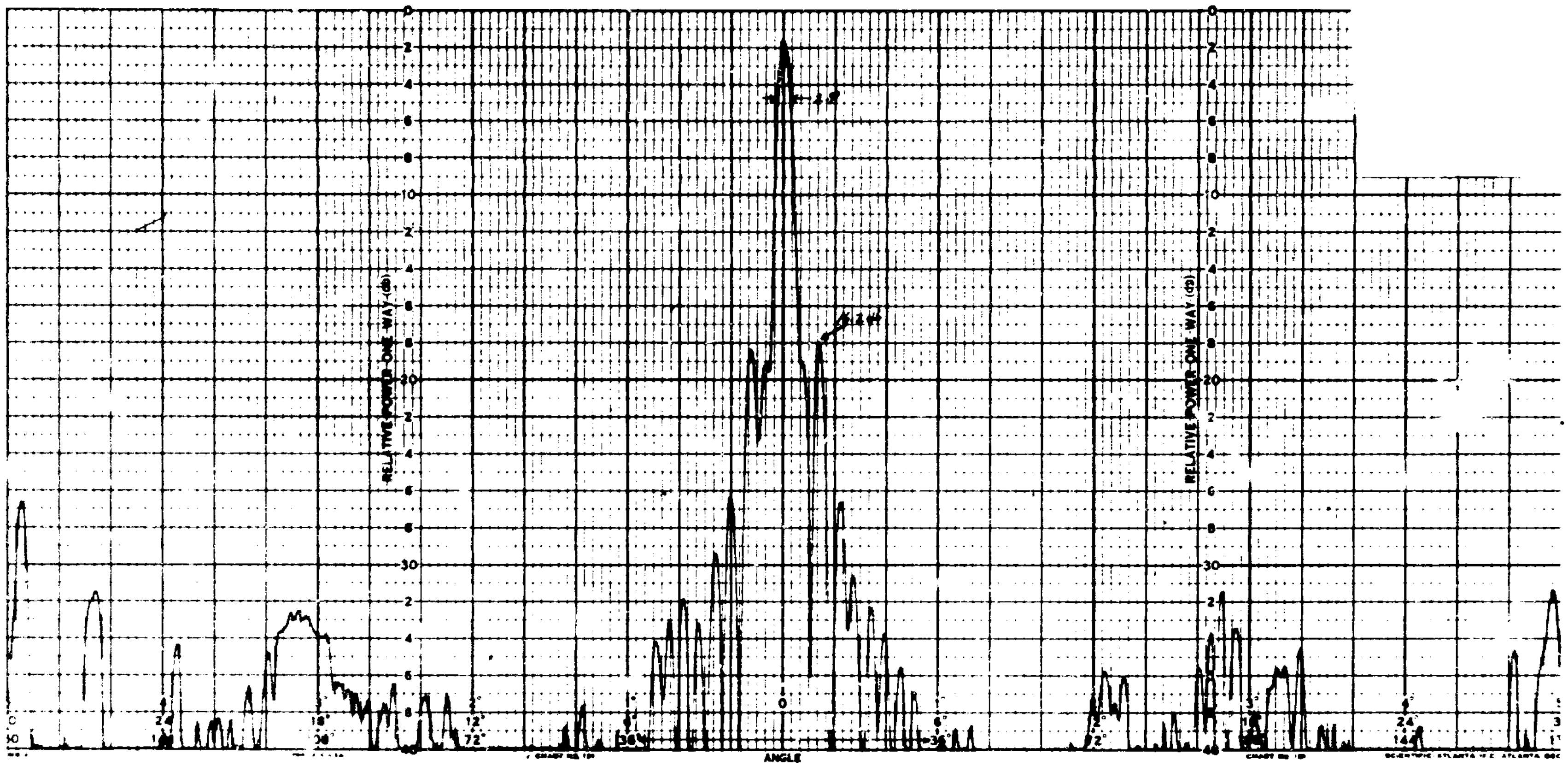
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 31 2.? GHz E-PLANE



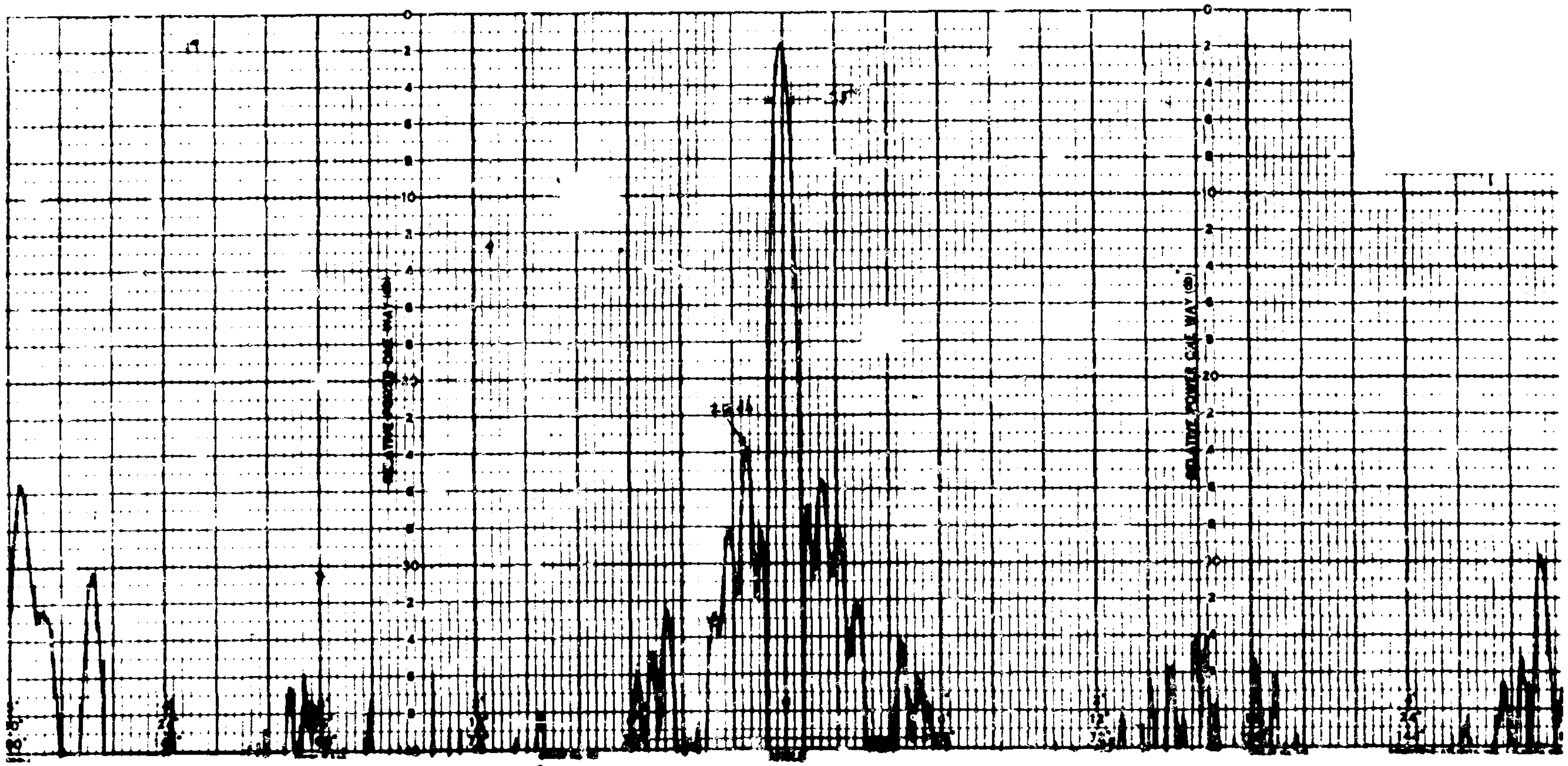
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 32 2.0 GHz H-PLANE



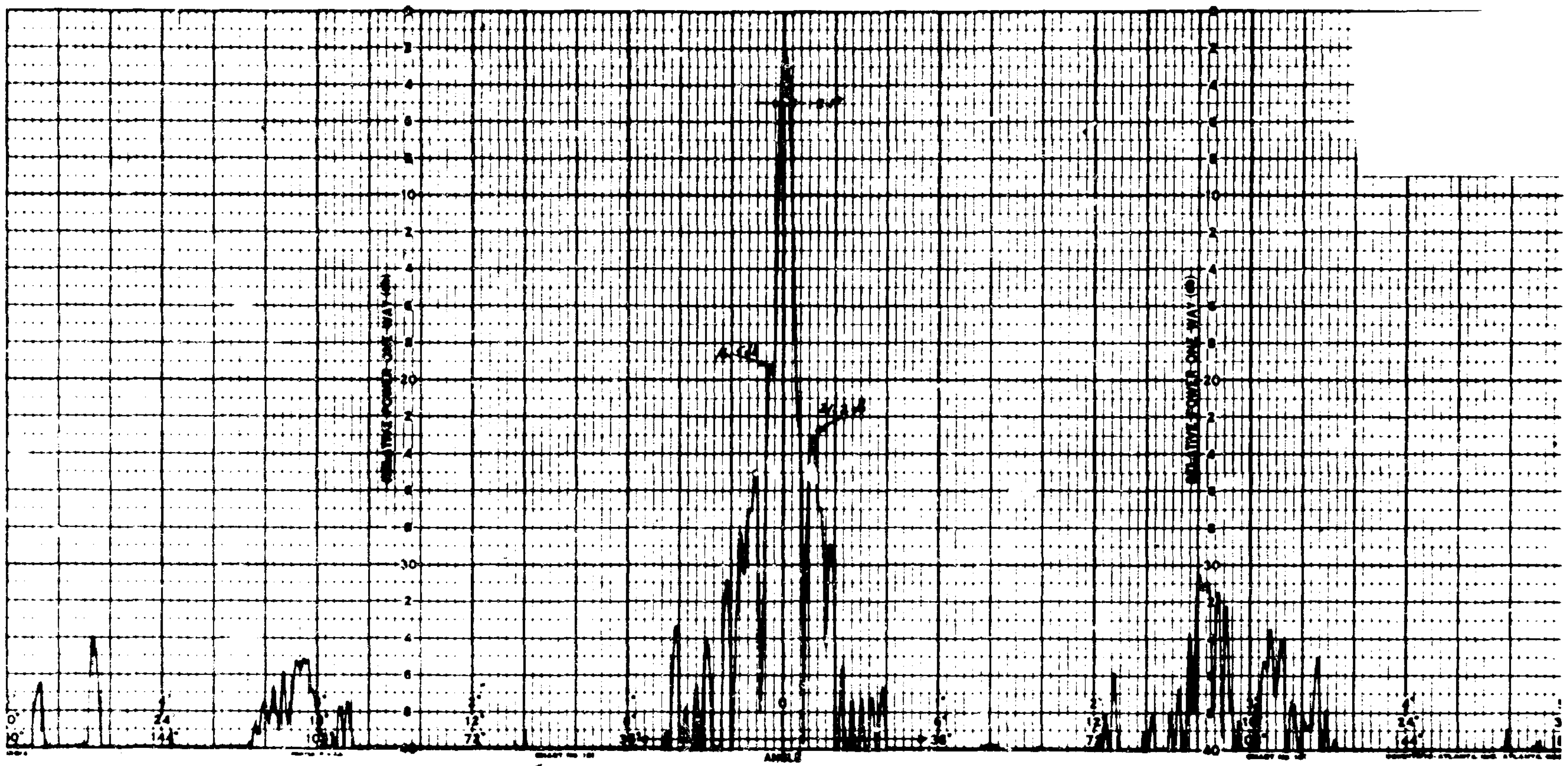
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 33 4.0 GHz E-PLANE



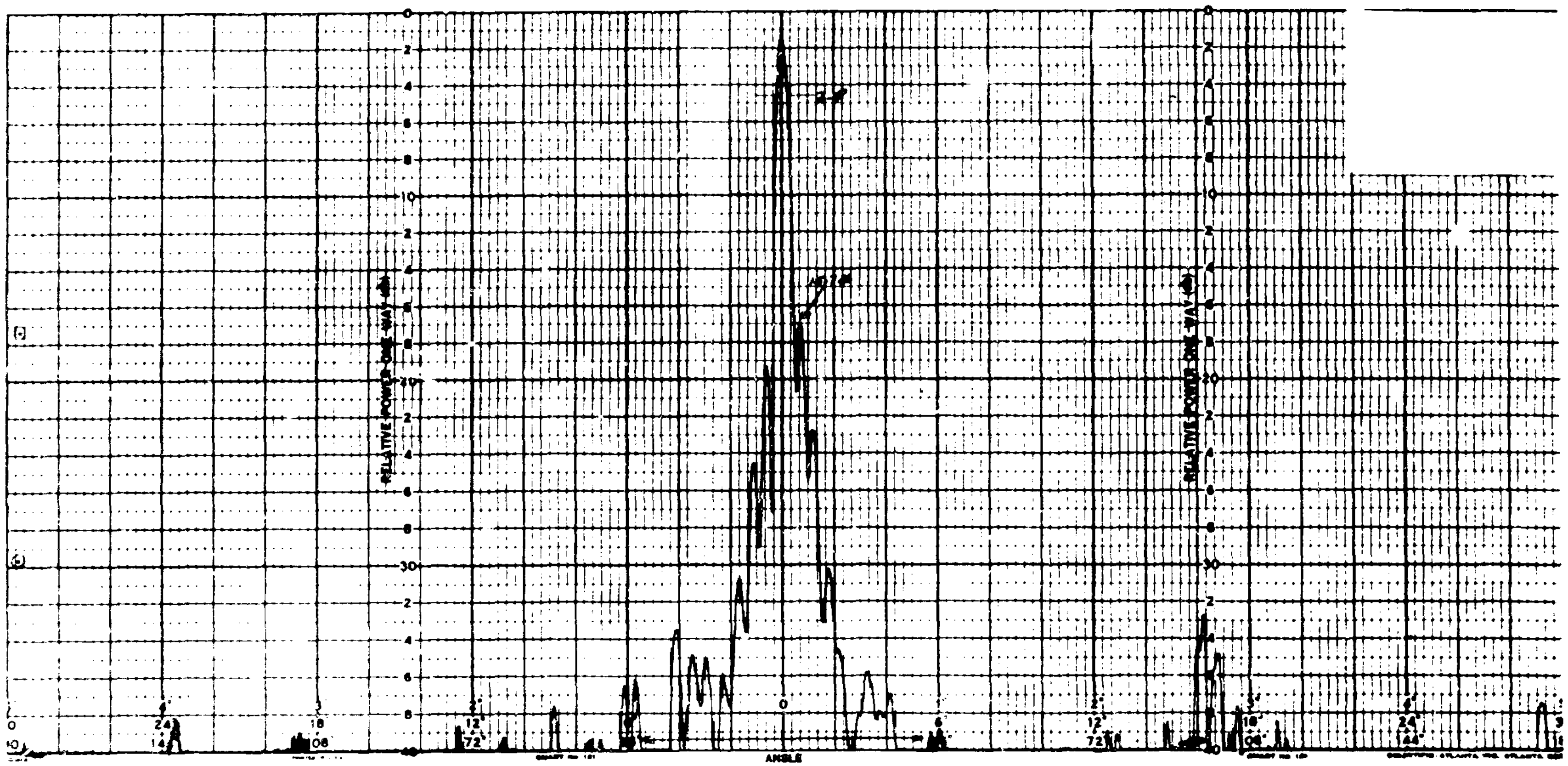
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 34 4.0 GHz E-PLANE



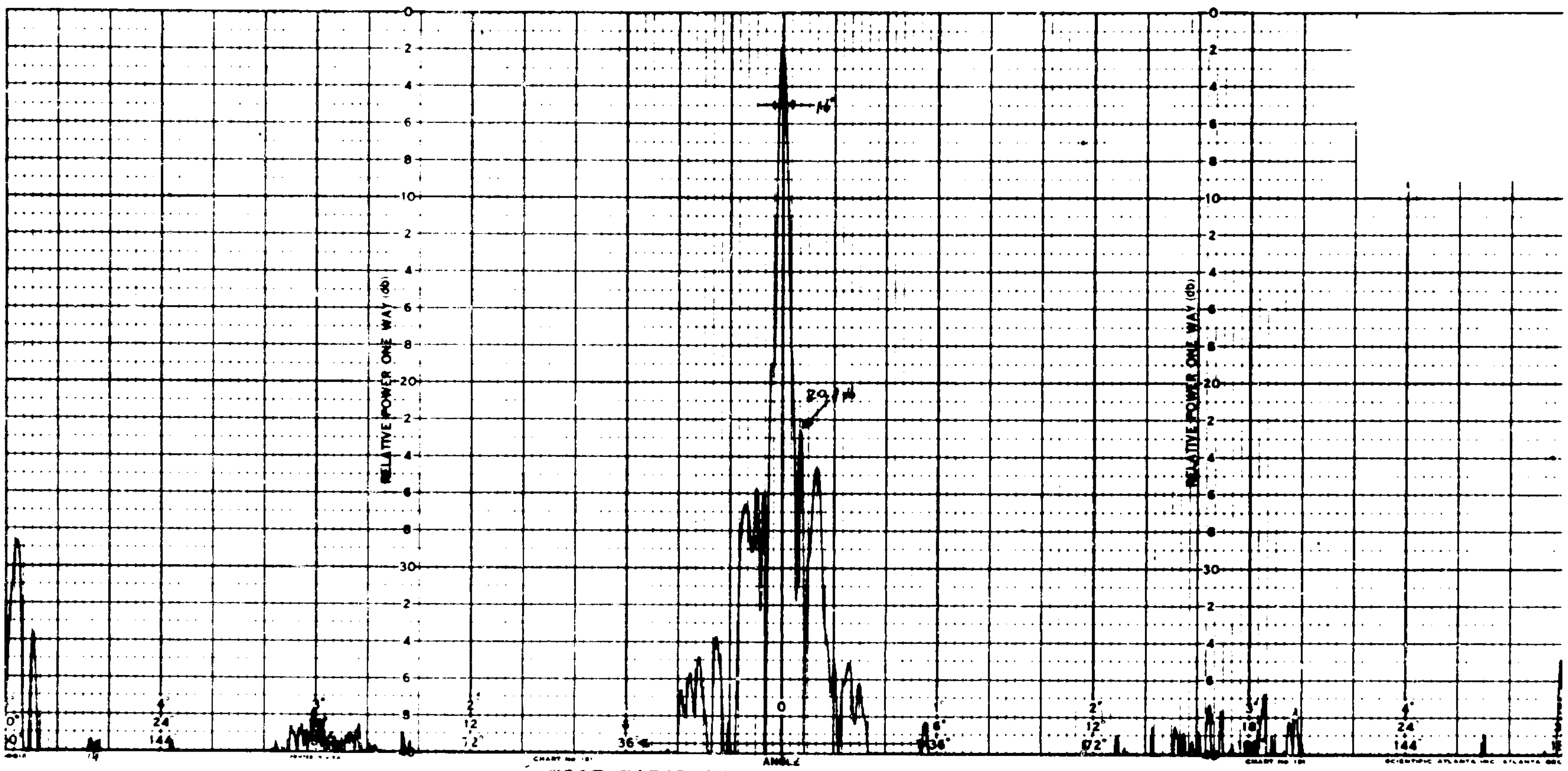
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 35 6.0 GHz E-PLANE



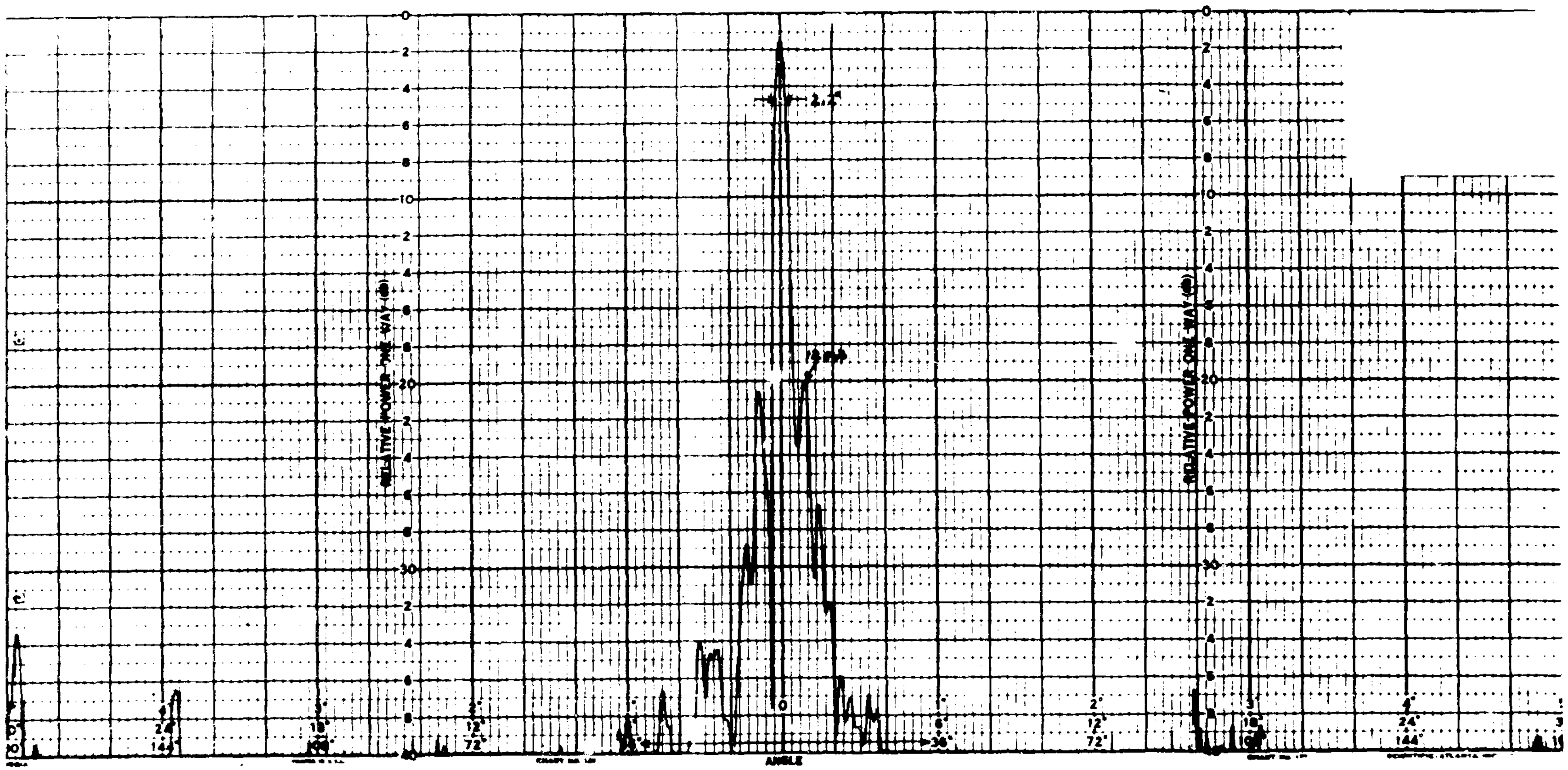
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 36 6.0 GHz H-PLANE



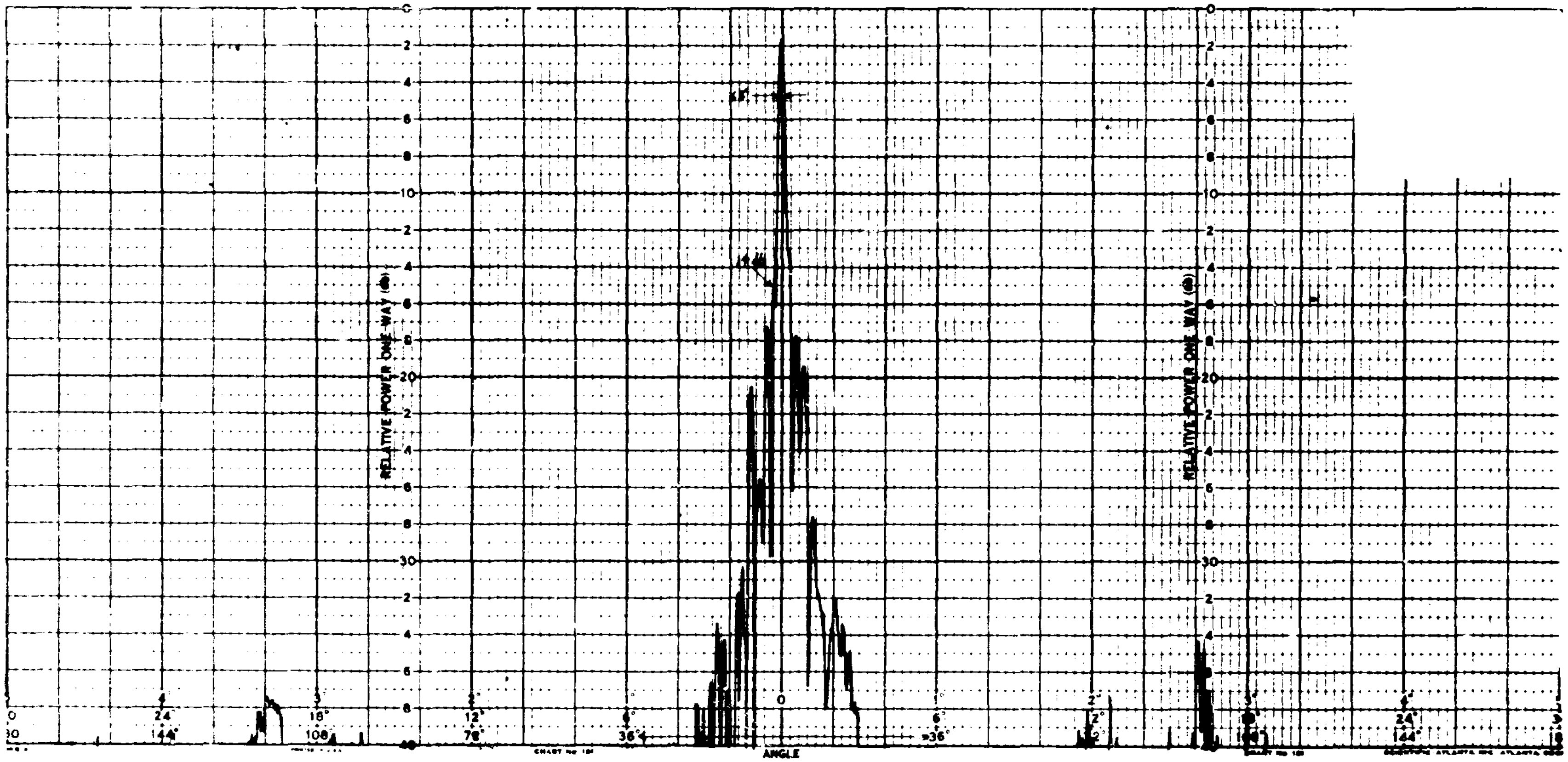
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 37 8.0 GHz [illegible]-PLANE



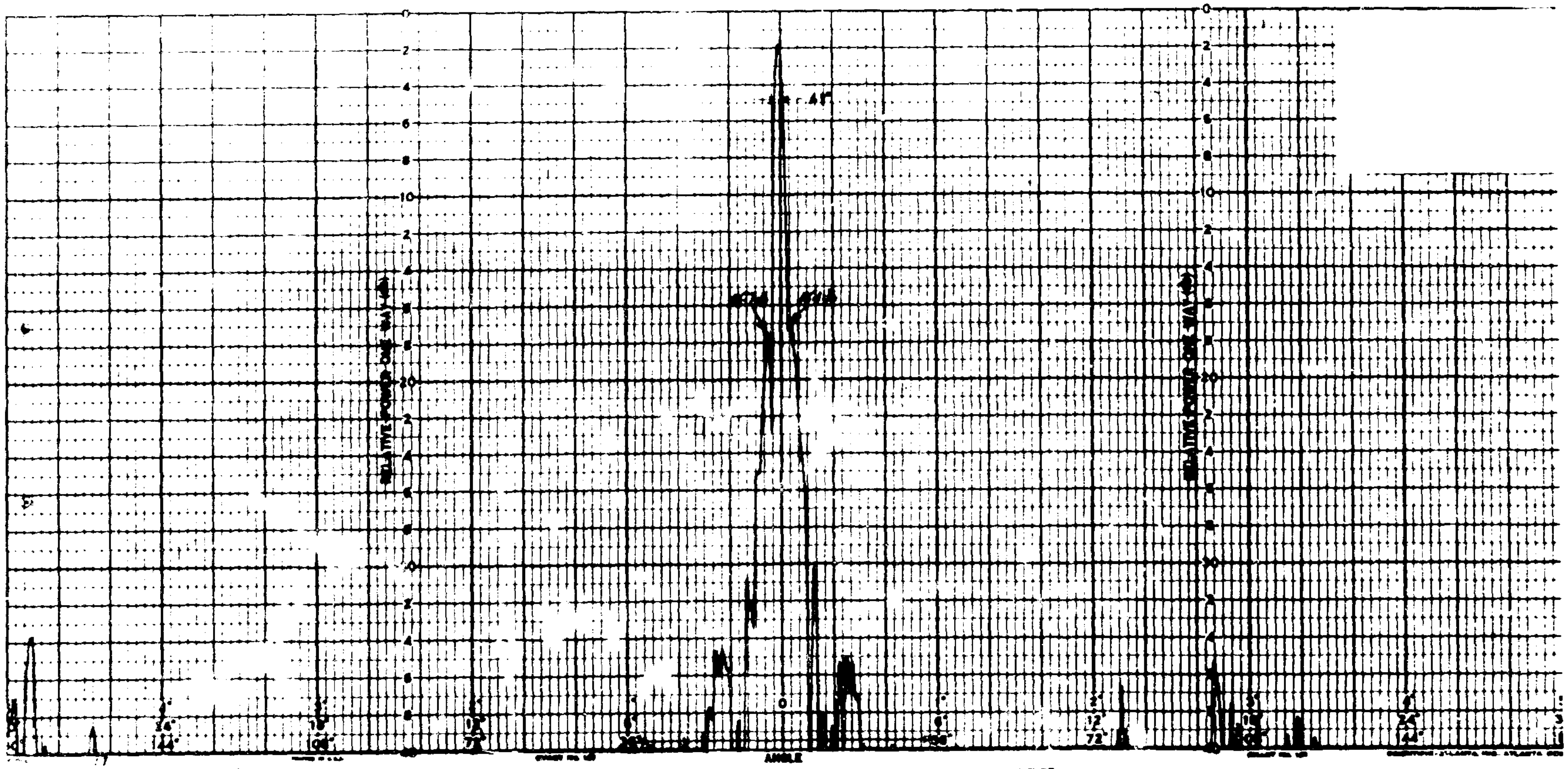
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 38 8.0 GHz H-PLANE



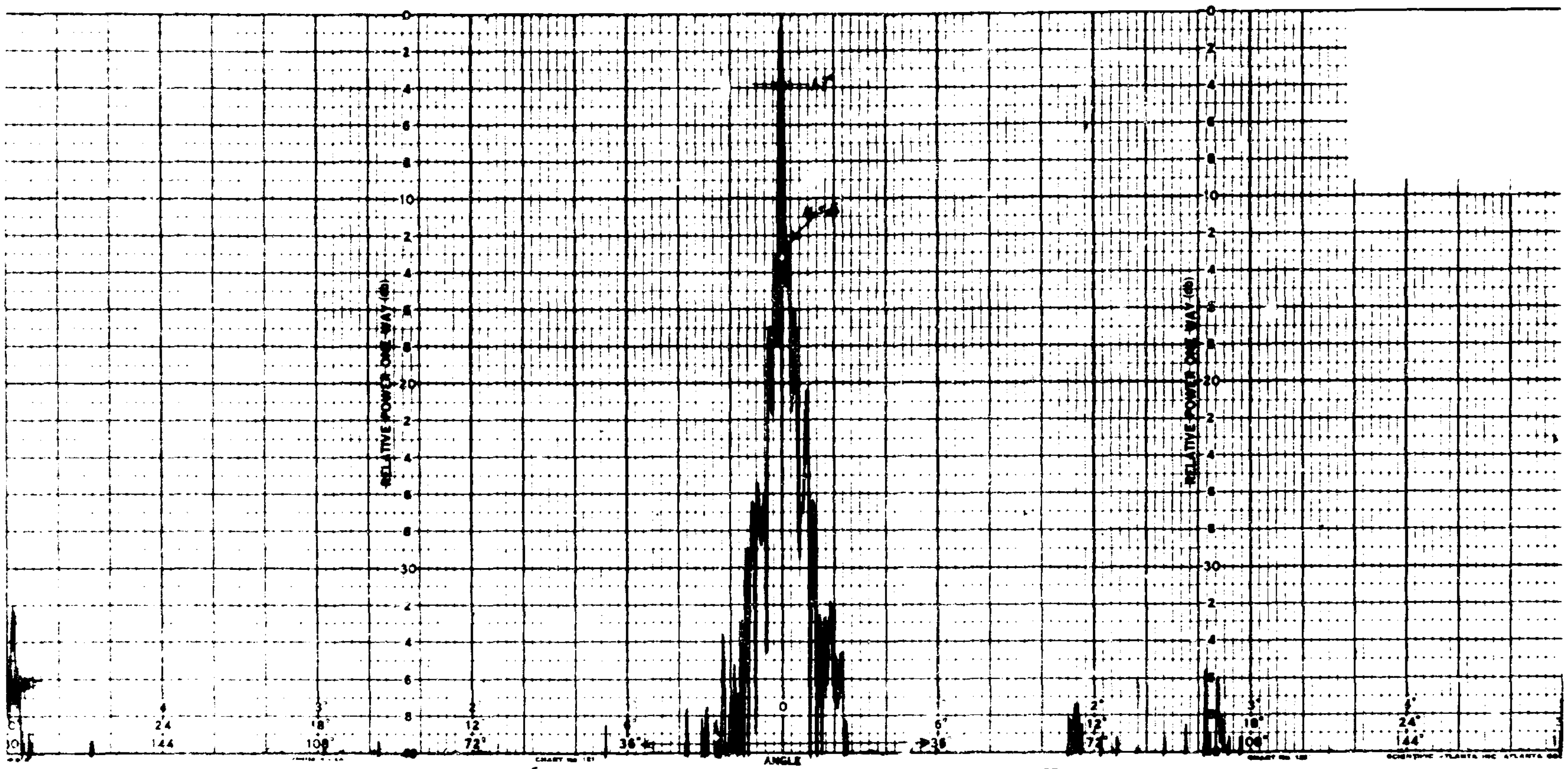
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 39 10.0 GHz E-PLANE



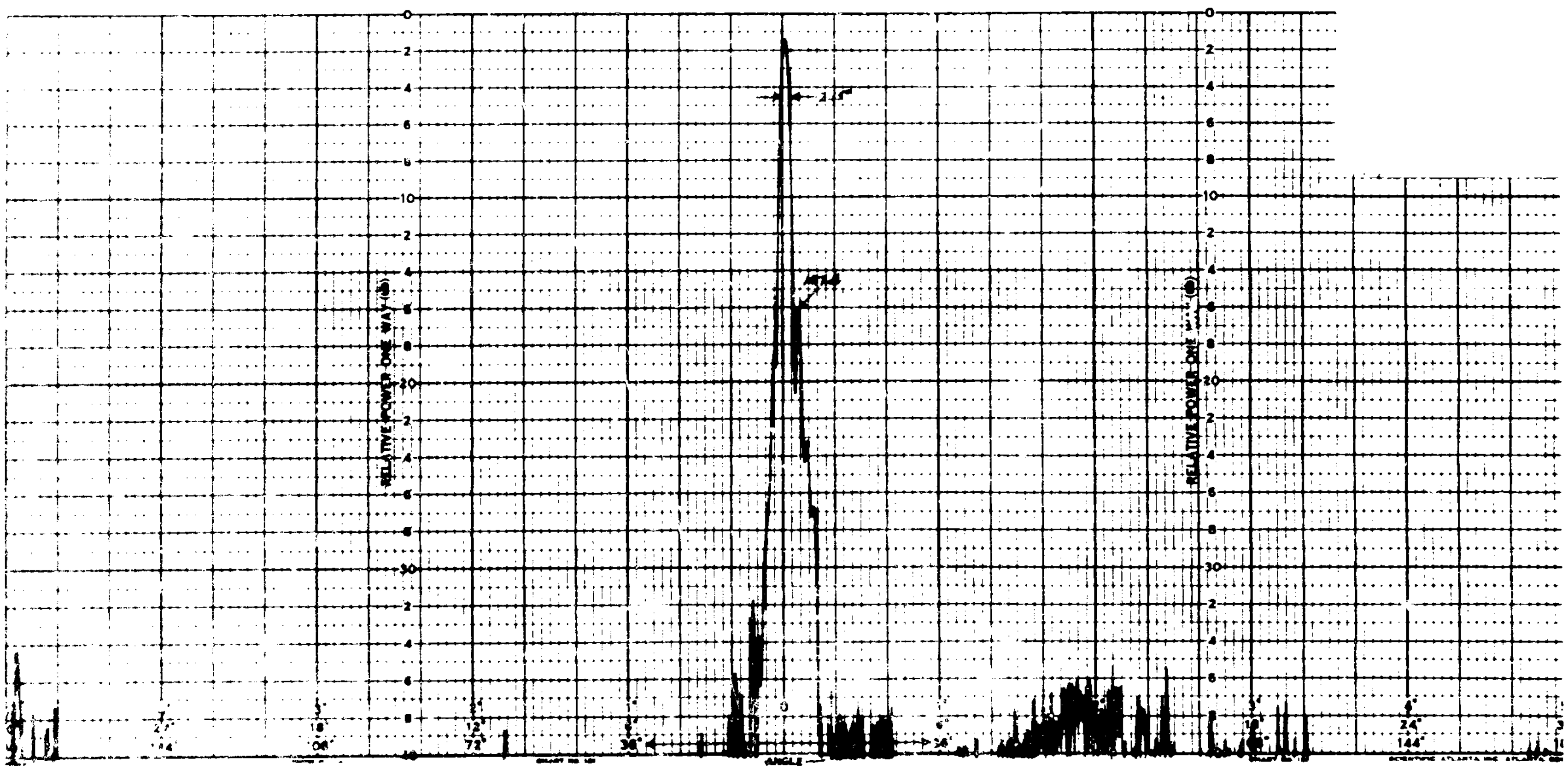
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 40 10.0 GHz H-PLANE



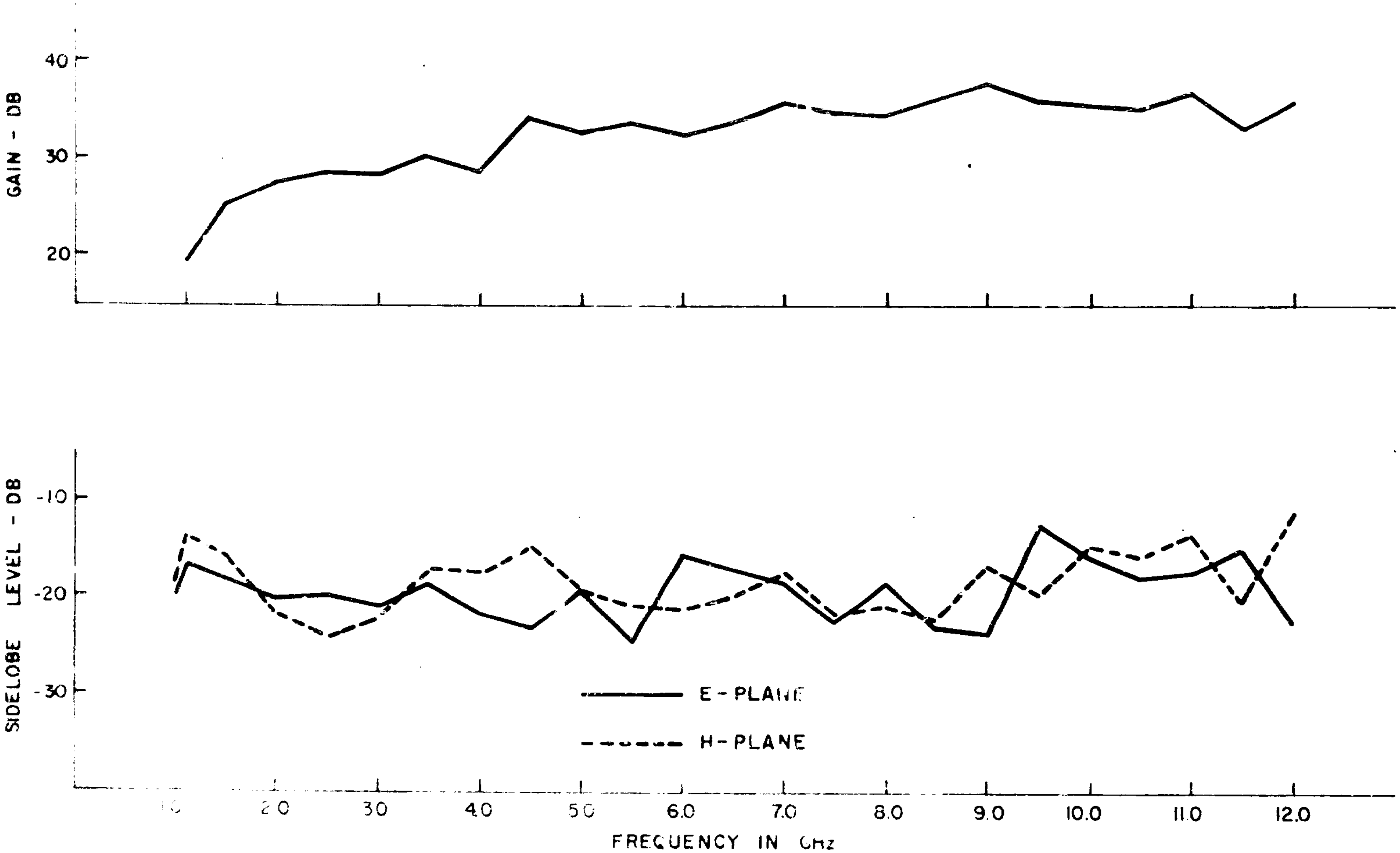
6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 41   12.0 GHz E-PLANE



6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 42 12.0 GHz H-PLANE



6-FOOT PARABOLA - BROADBAND FEED HORN

FIGURE 43 - GAIN AND SIDE-LOBE LEVEL

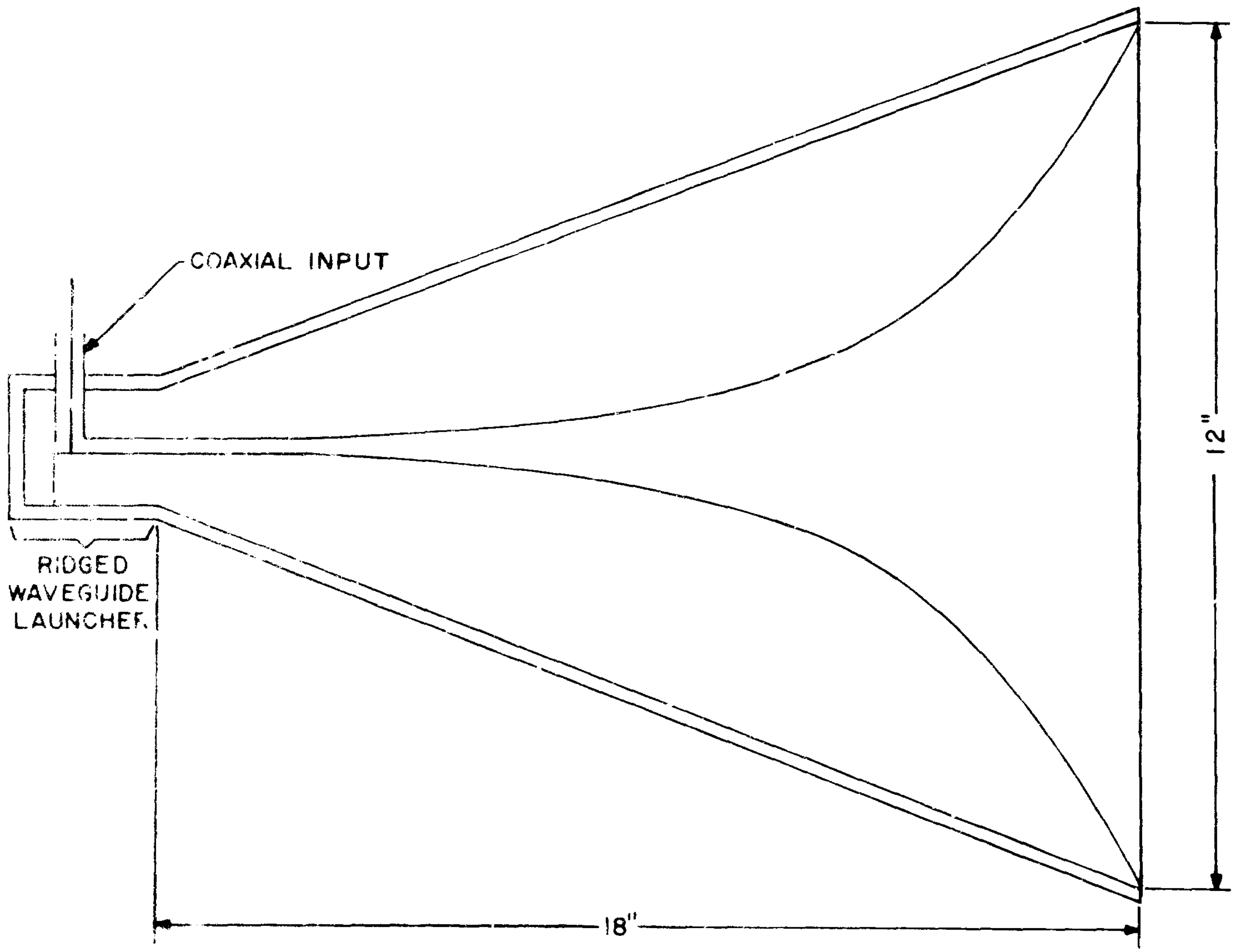
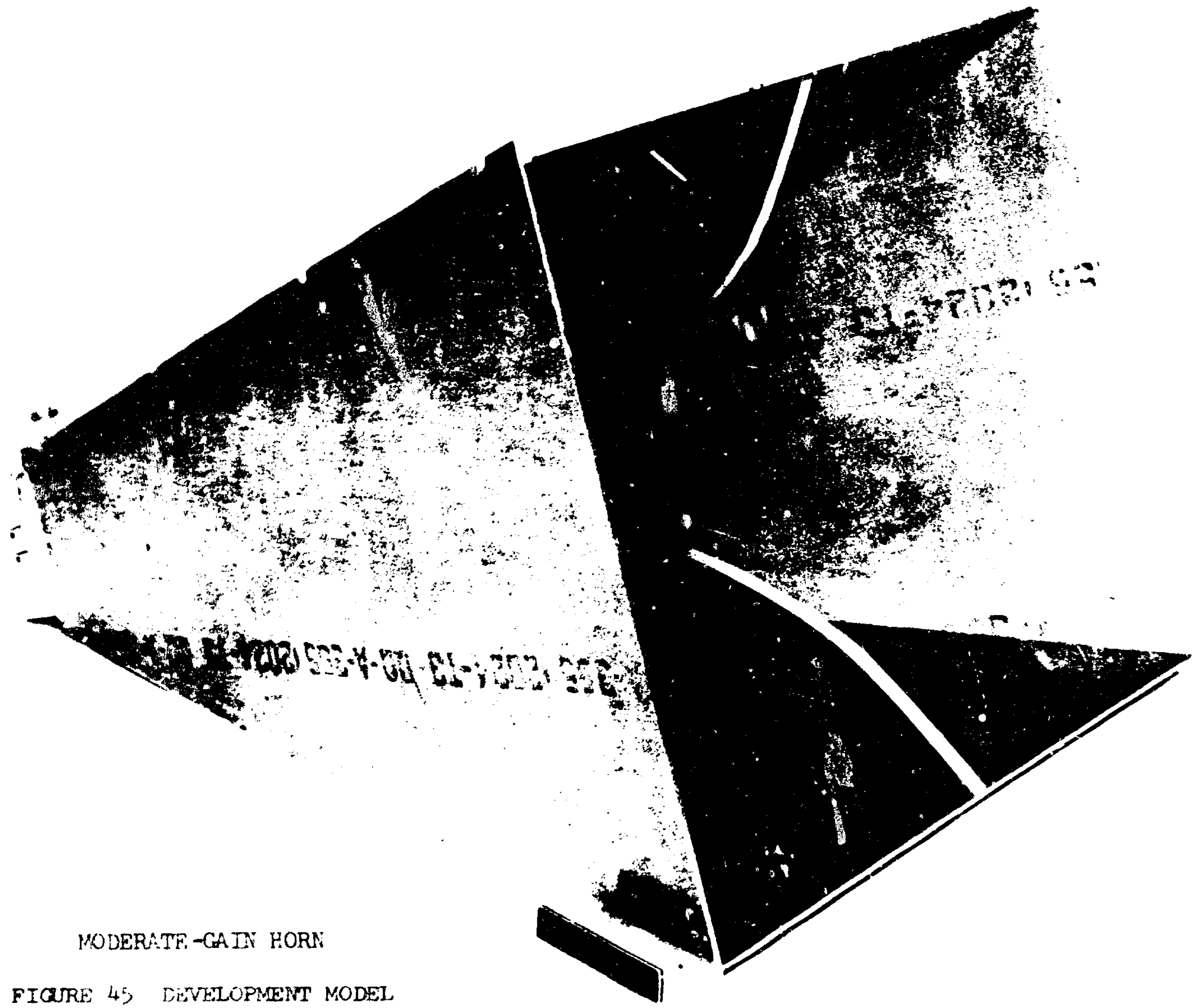
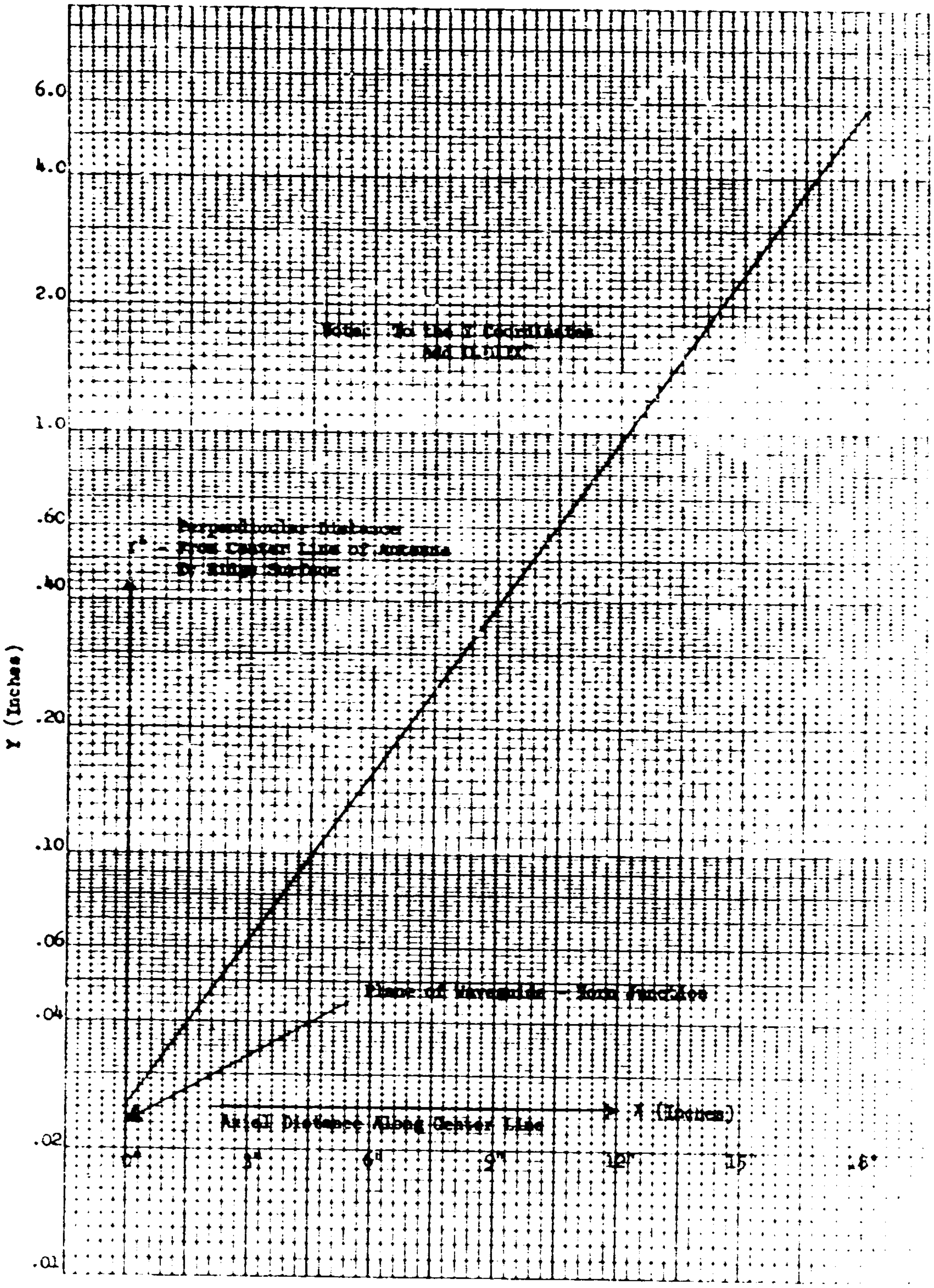


FIGURE 44 MODERATE-GAIN HORN



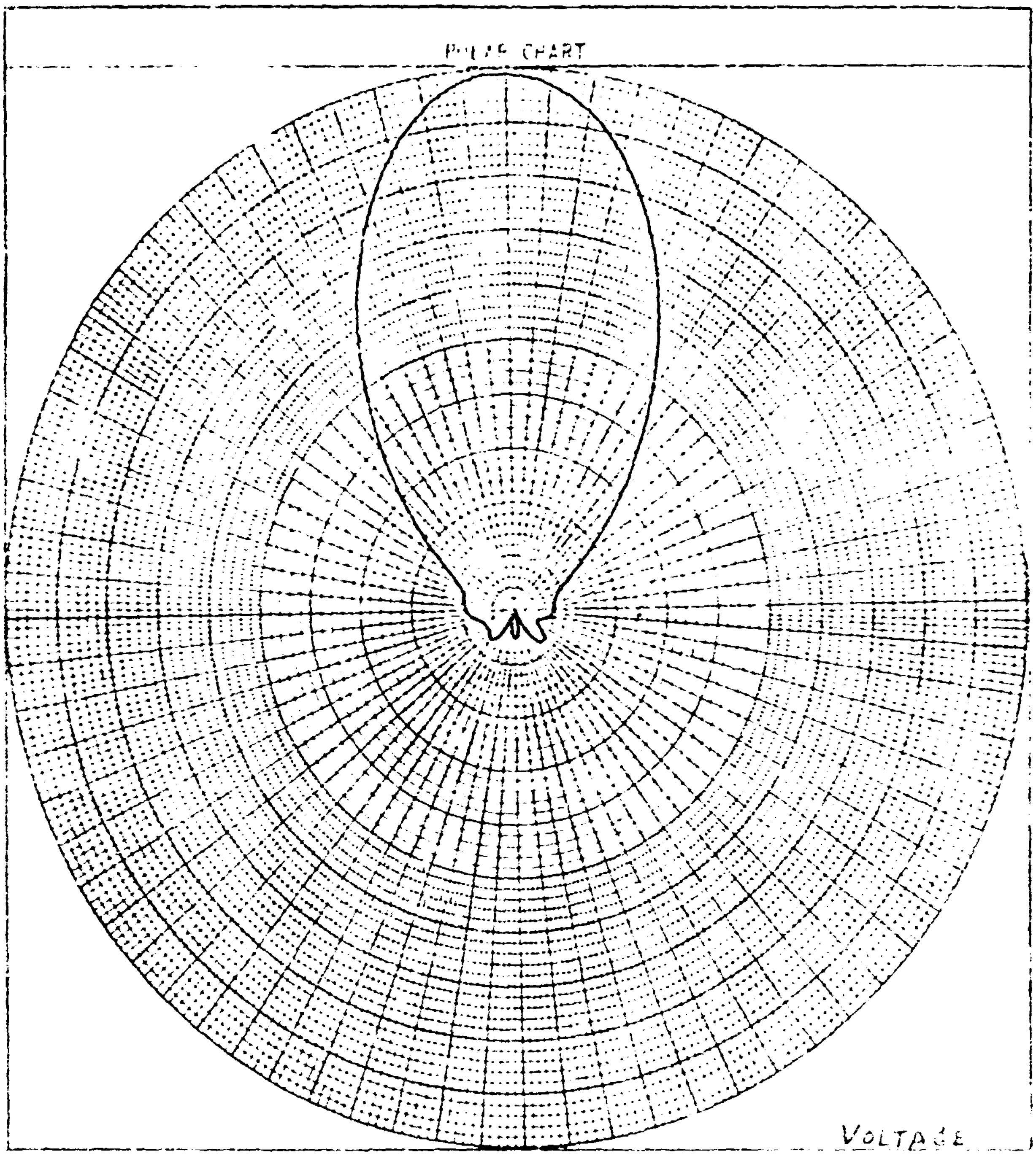
MODERATE-GAIN HORN

FIGURE 45 DEVELOPMENT MODEL



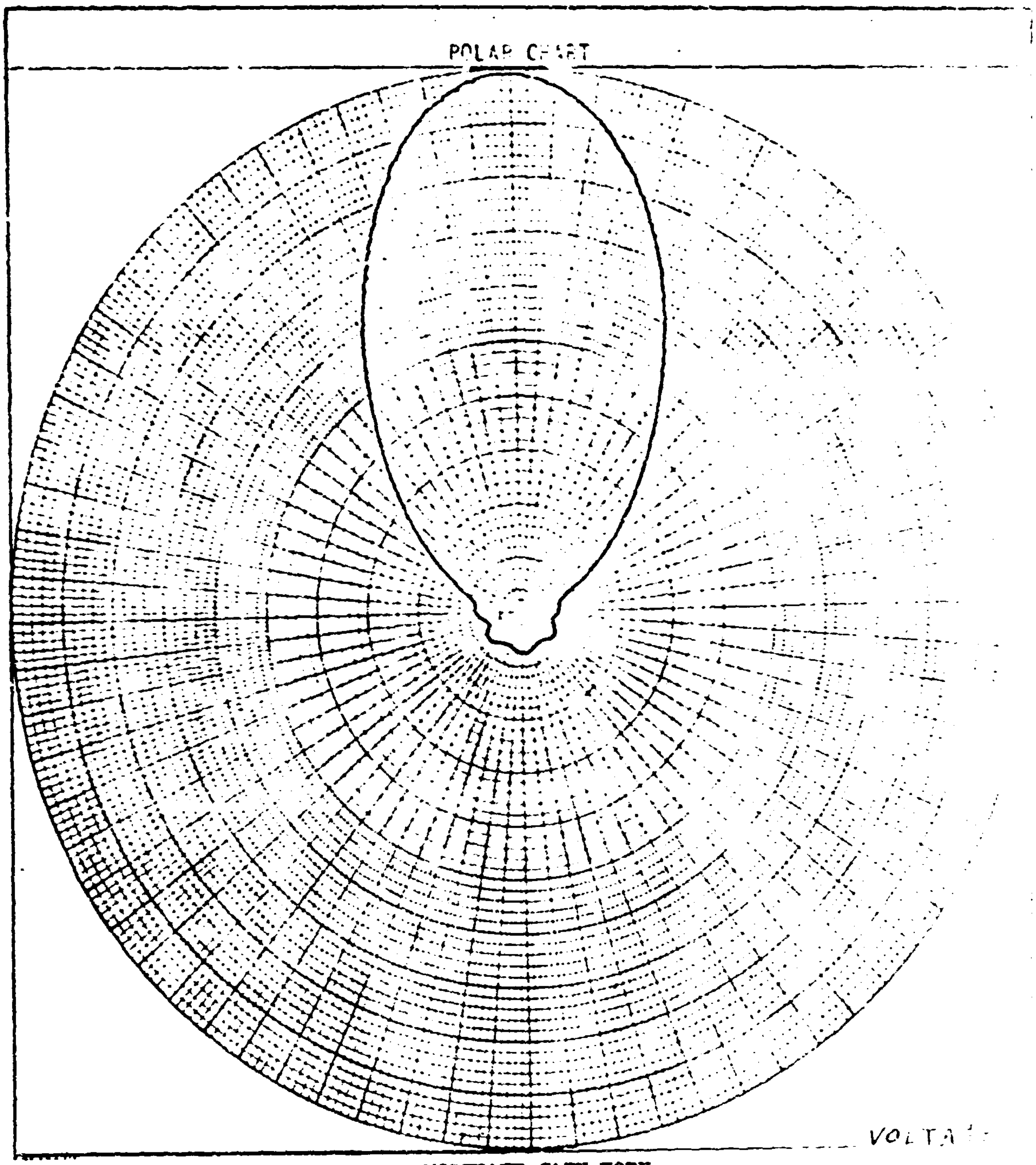
MODERATE-GAIN HORN

FIGURE 46 - RIDGE CURVE COORDINATES



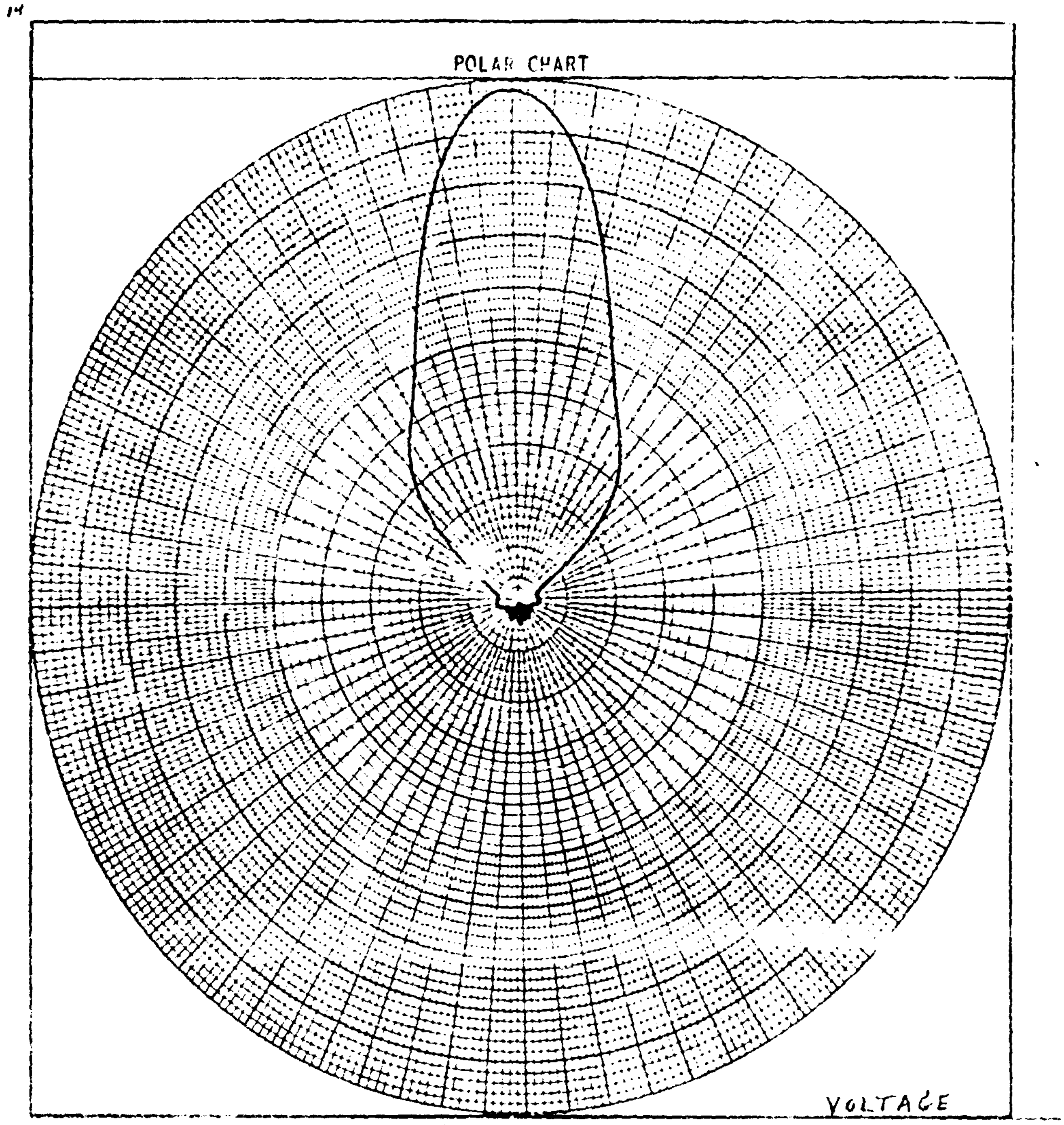
MODERATE-GAIN HORN

FIGURE 47 1.0 GHz E-PLANE



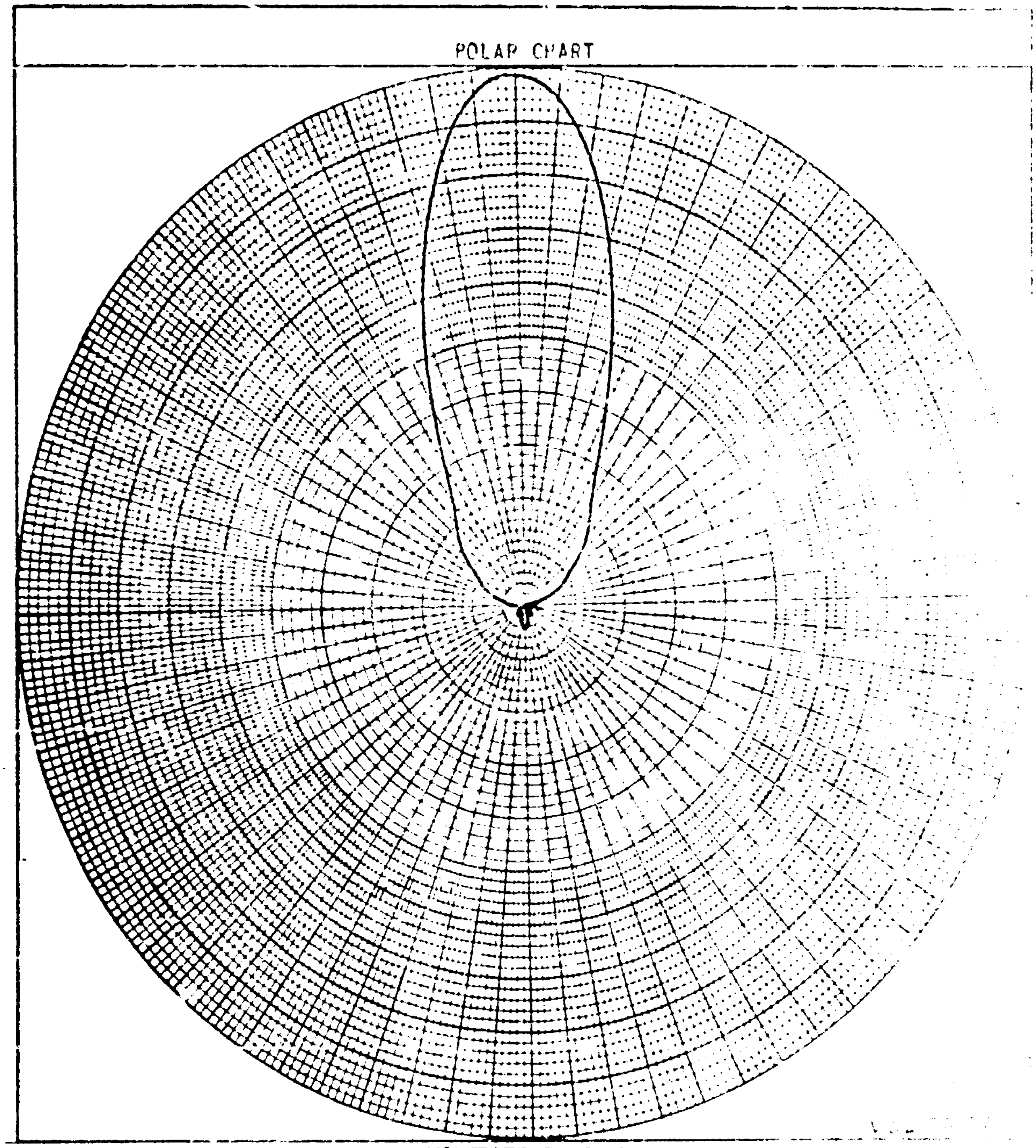
MODERATE-GAIN HORN

FIGURE 48 1.0 GHz H-PLANE



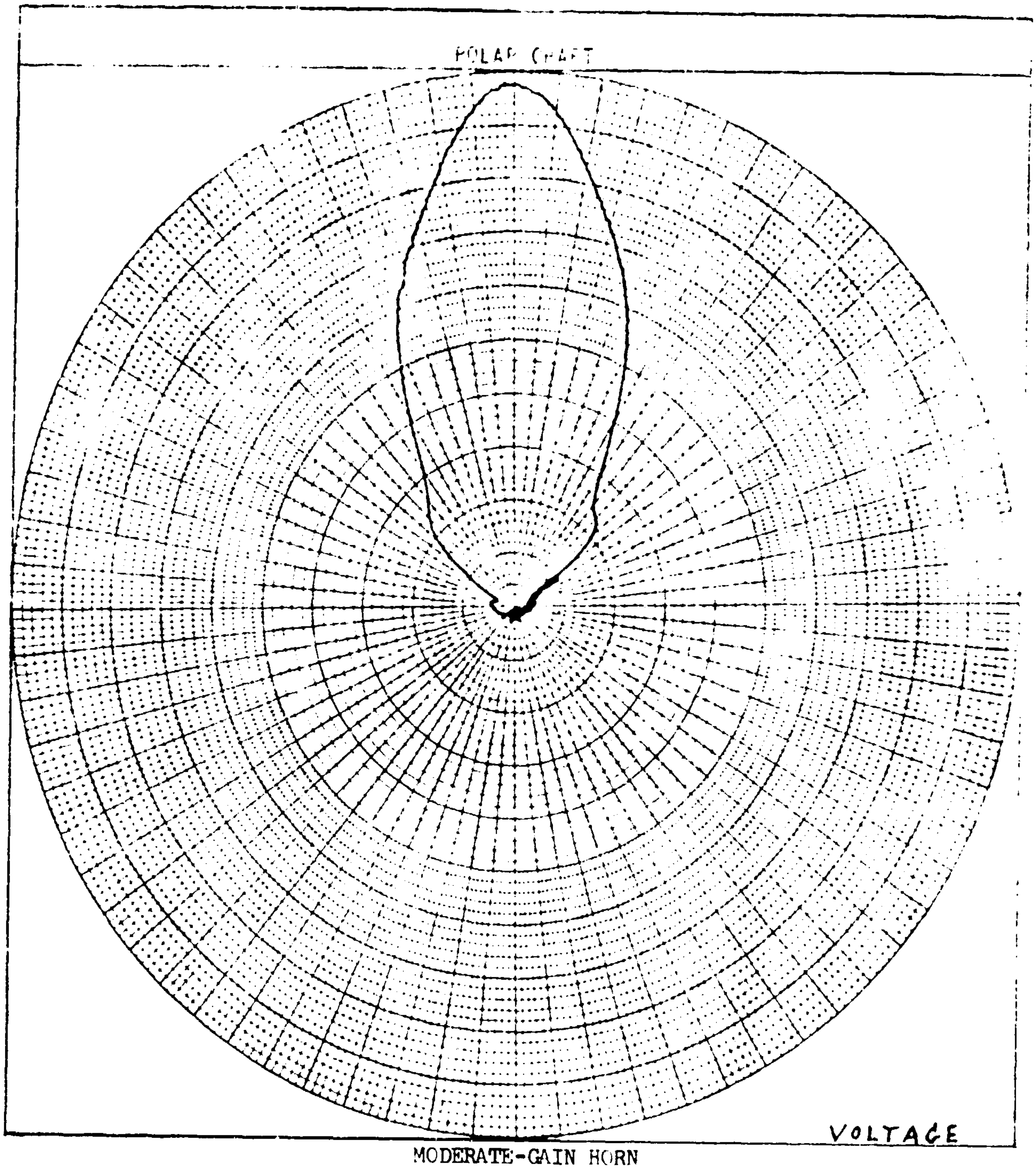
MODERATE-GAIN HORN

FIGURE 49 2.0 GHz E-PLANE



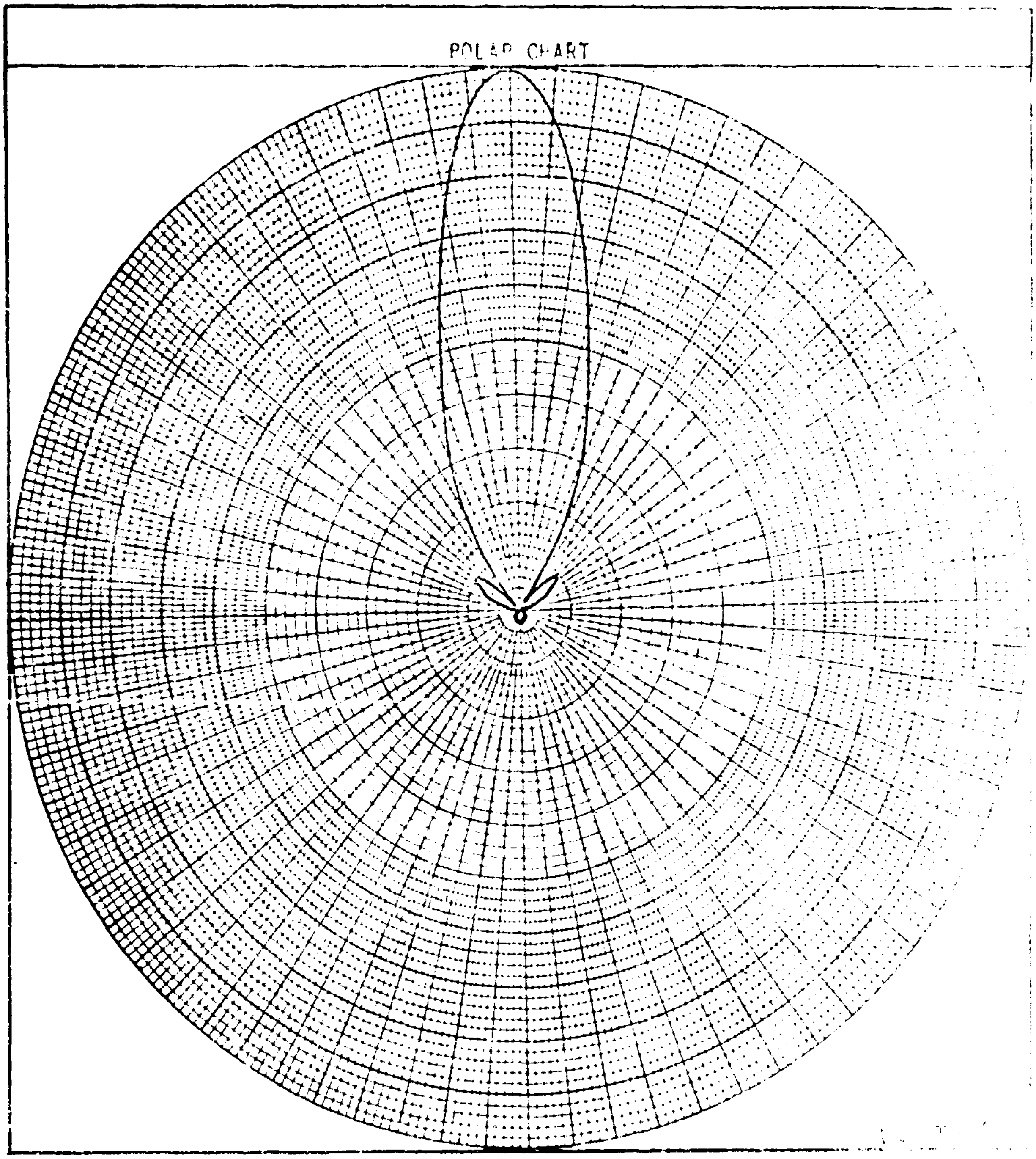
MODERATE-GAIN HORN

FIGURE 50 2.0 GHz H-PLANE



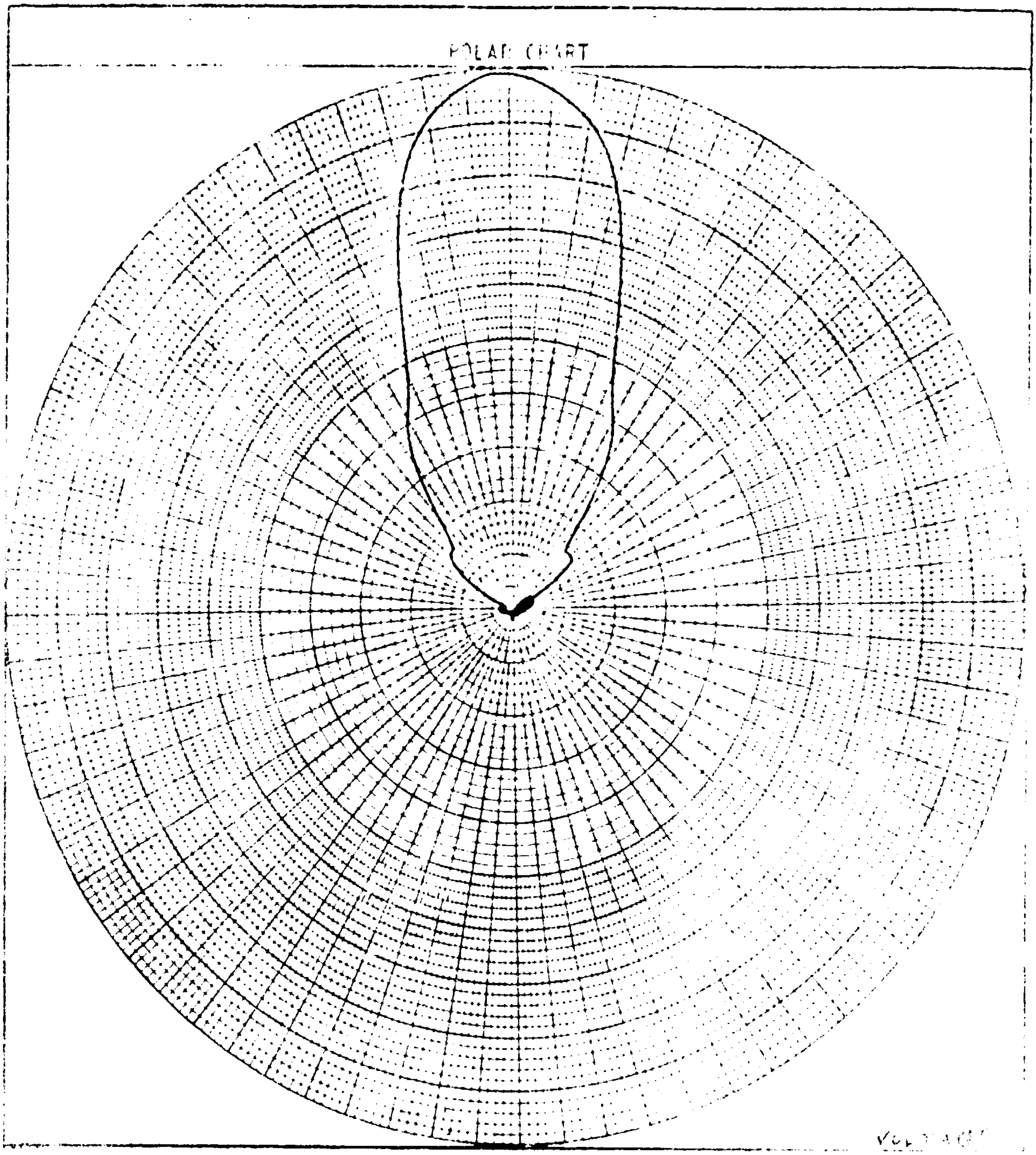
MODERATE-GAIN HORN

FIGURE 51 3.0 GHz E-PLANE



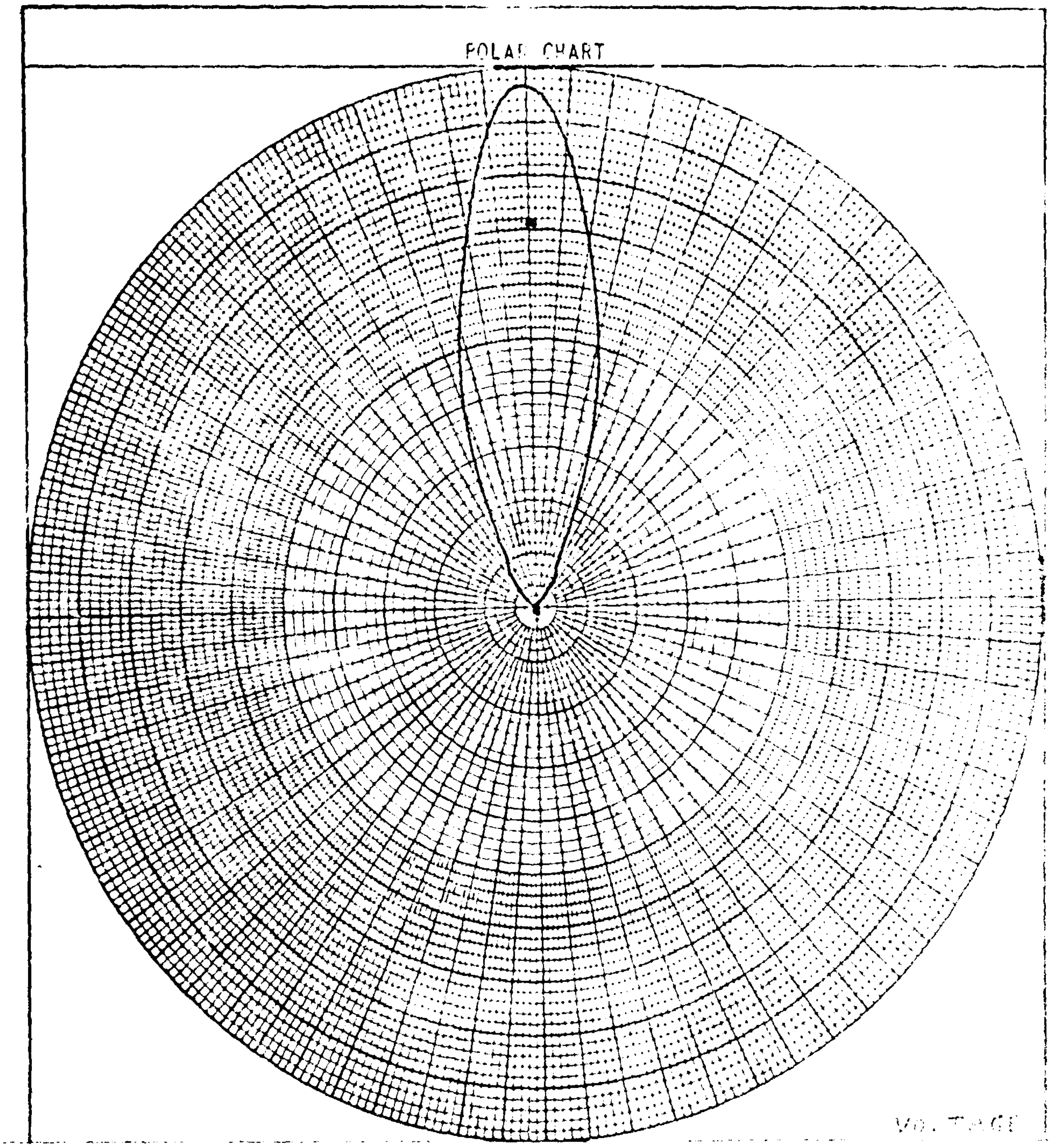
MODERATE-GAIN HORN

FIGURE 52 3.0 GHz H-PLANE



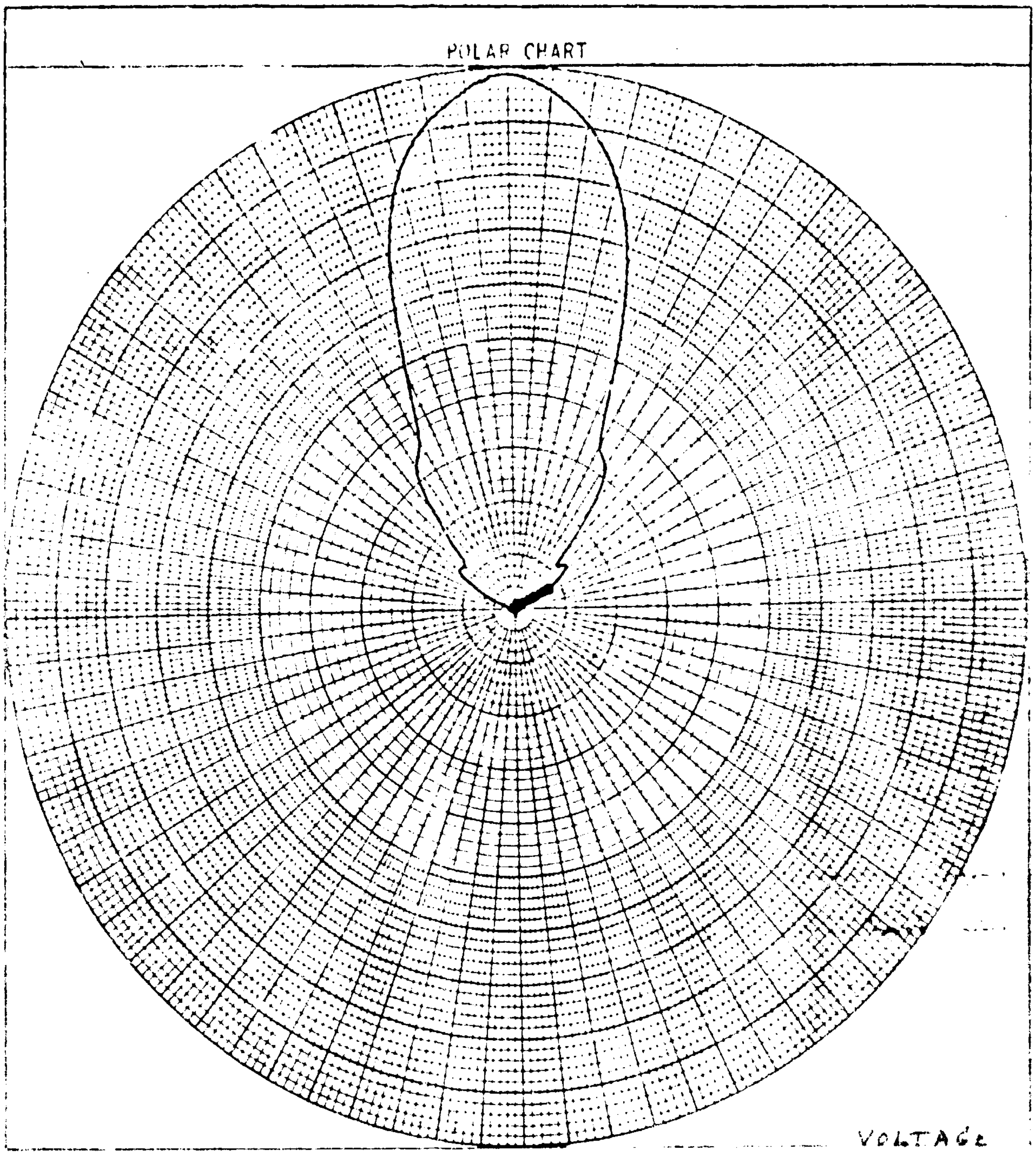
MODERATE-GAIN HORN

FIGURE 53 4.0 GHz E-PLANE



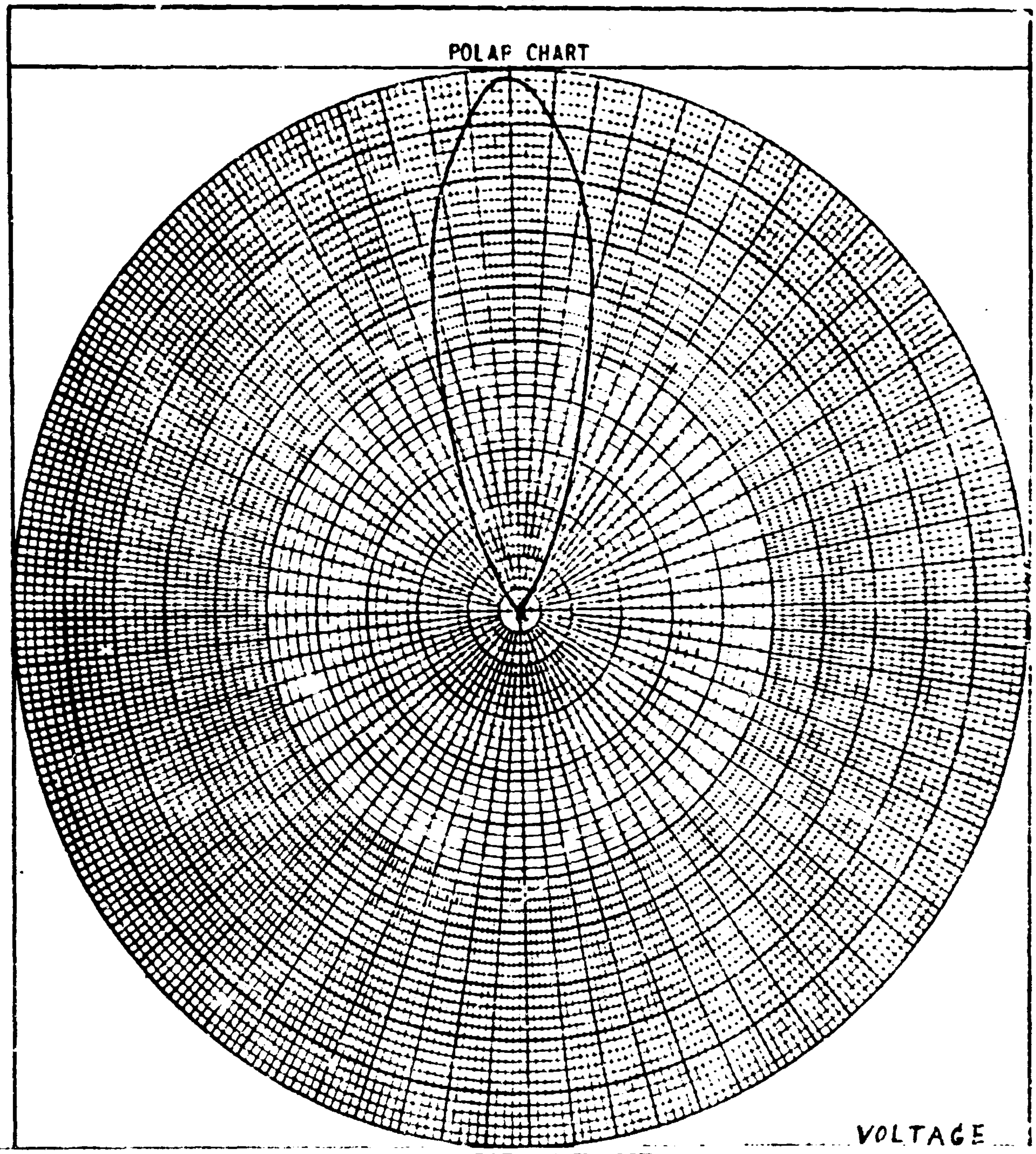
MODERATE-GAIN HORN

FIGURE 54 4.0 GHz H-PLANE



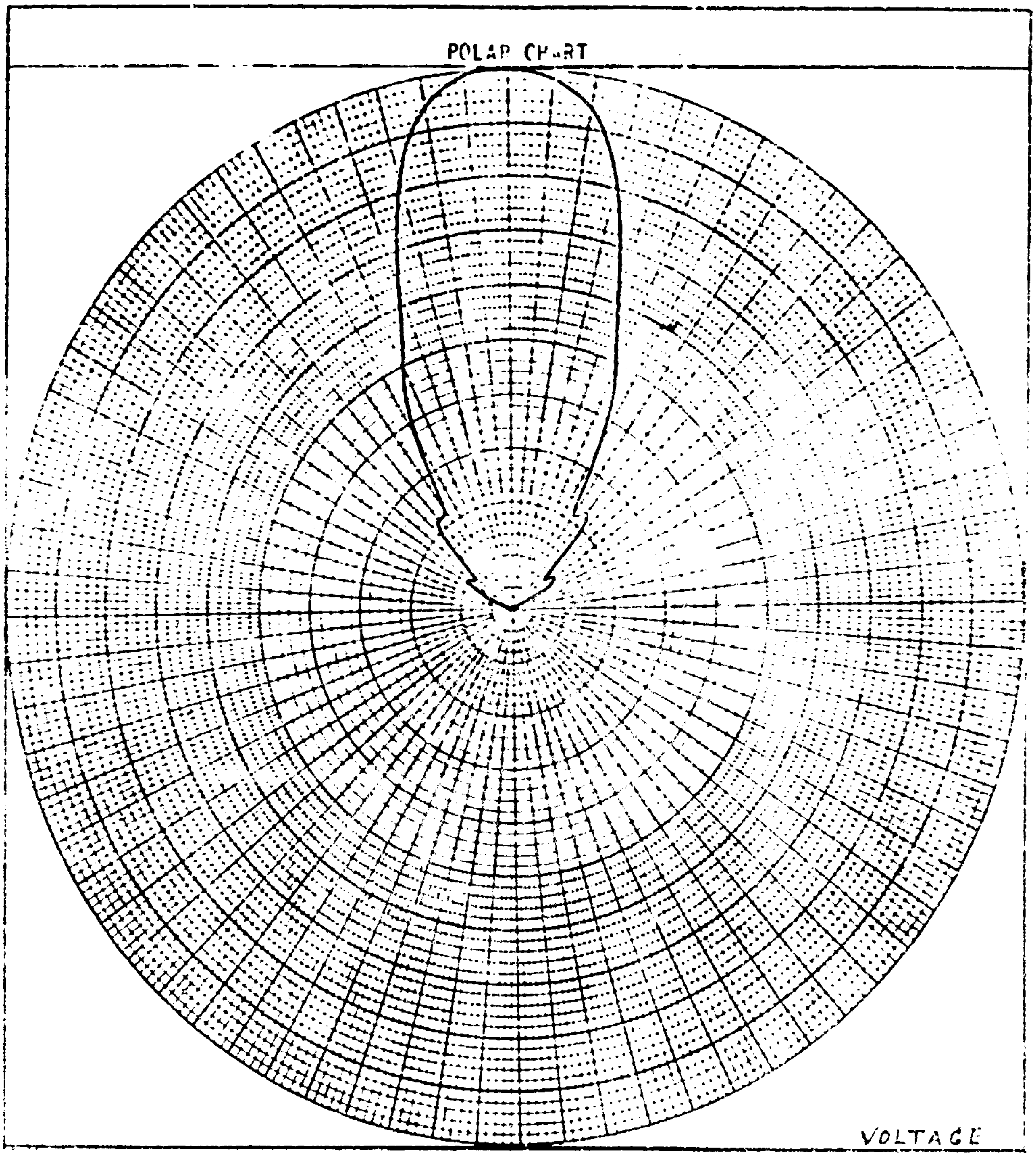
MODERATE-GAIN HORN

FIGURE 55 5.0 GHz E-PLANE



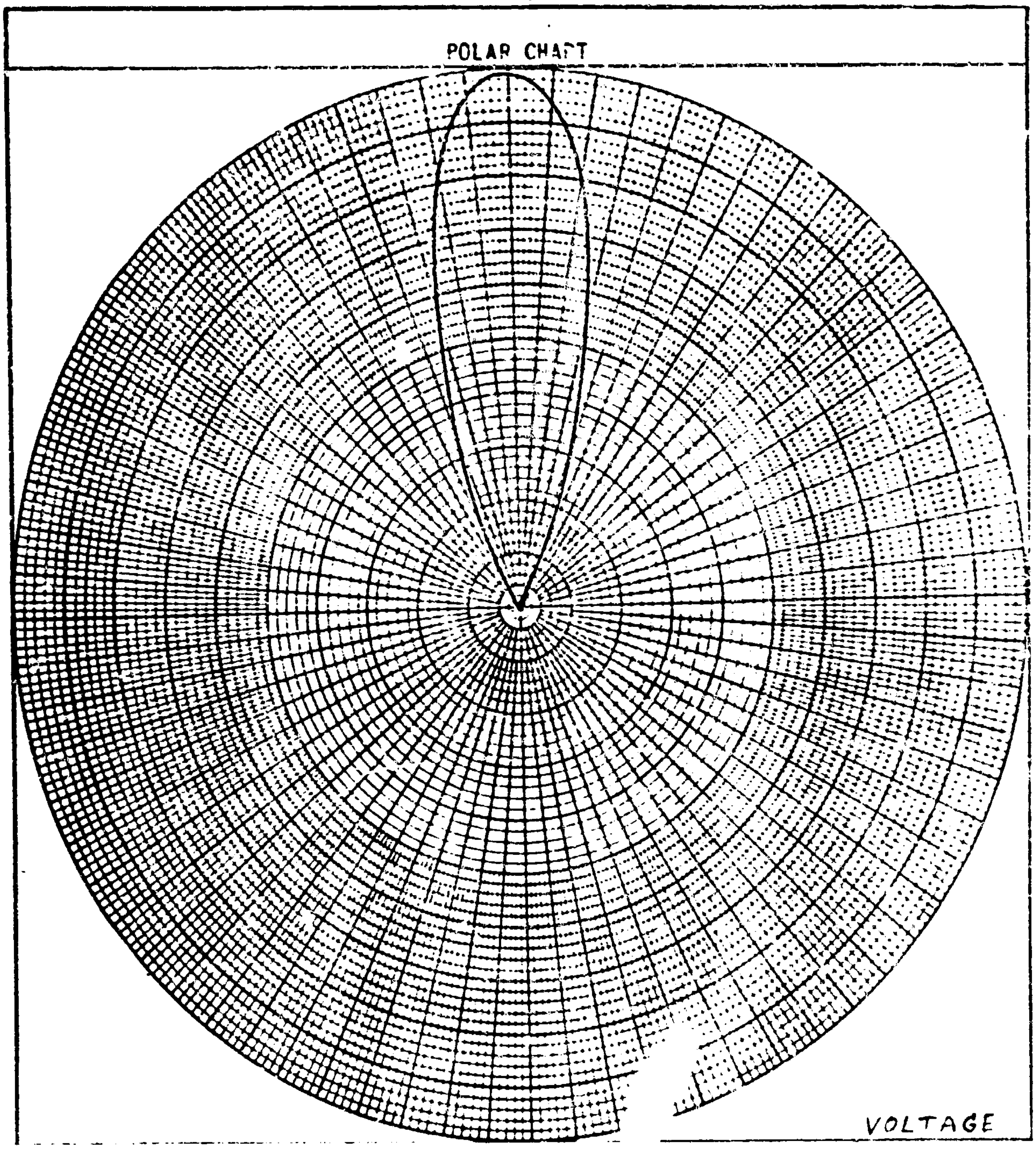
MODERATE-GAIN HORN

FIGURE 56 5.0 GHz H-PLANE



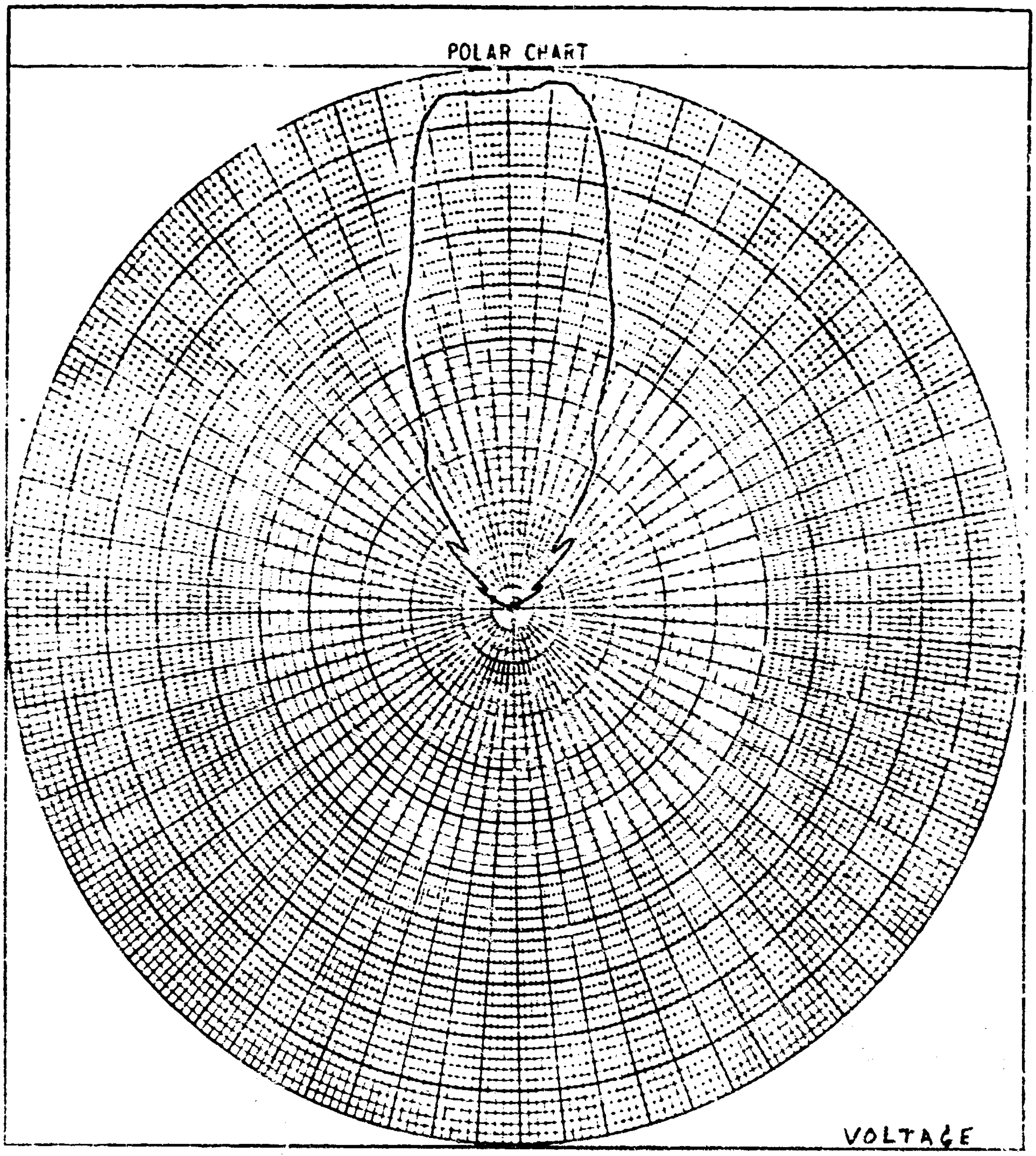
MODERATE-GAIN HORN

FIGURE 57 6.0 GHz E-PLANE



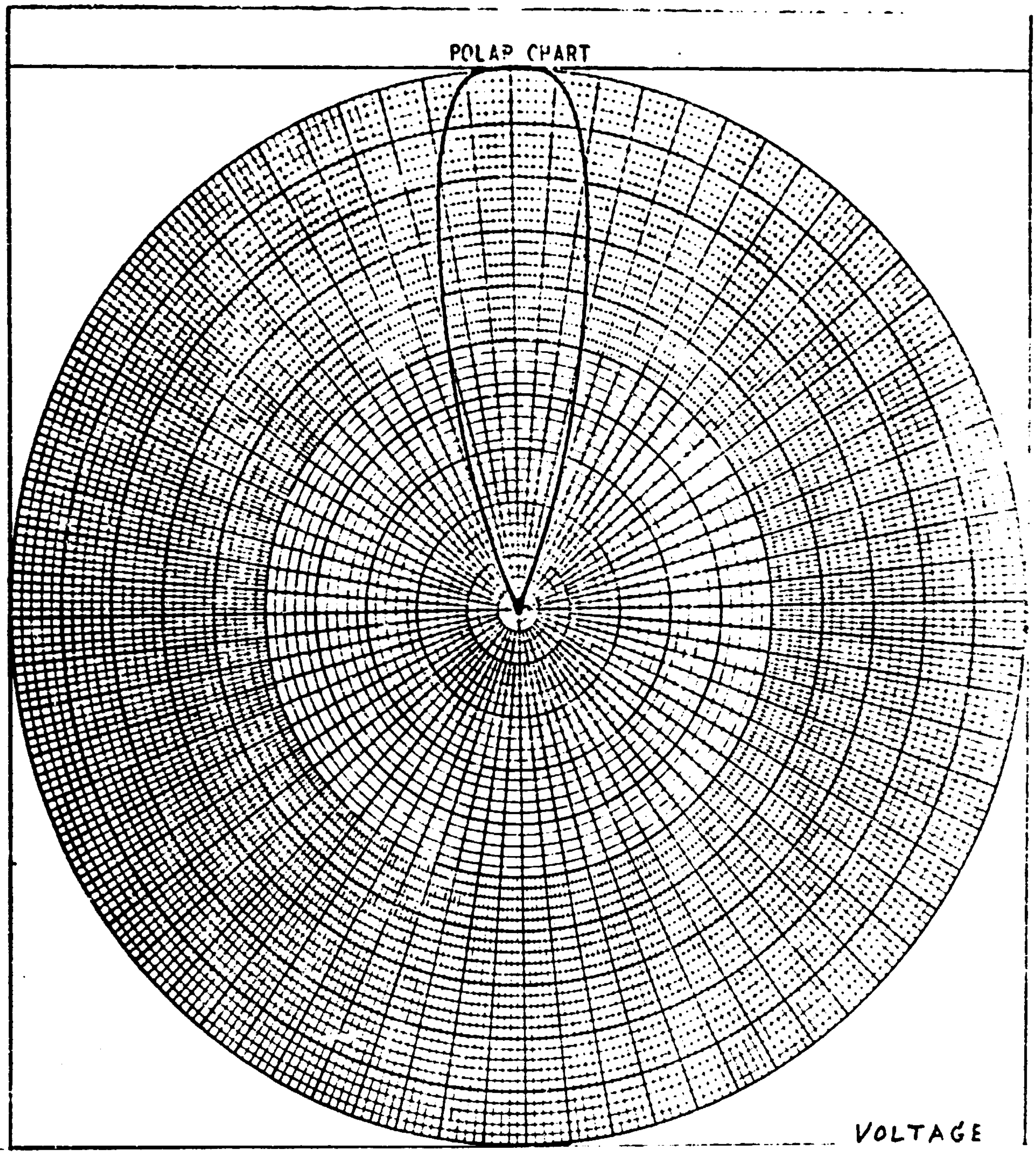
MODERATE-GAIN F . N

FIGURE 58 6.0 GHz H-PLANE



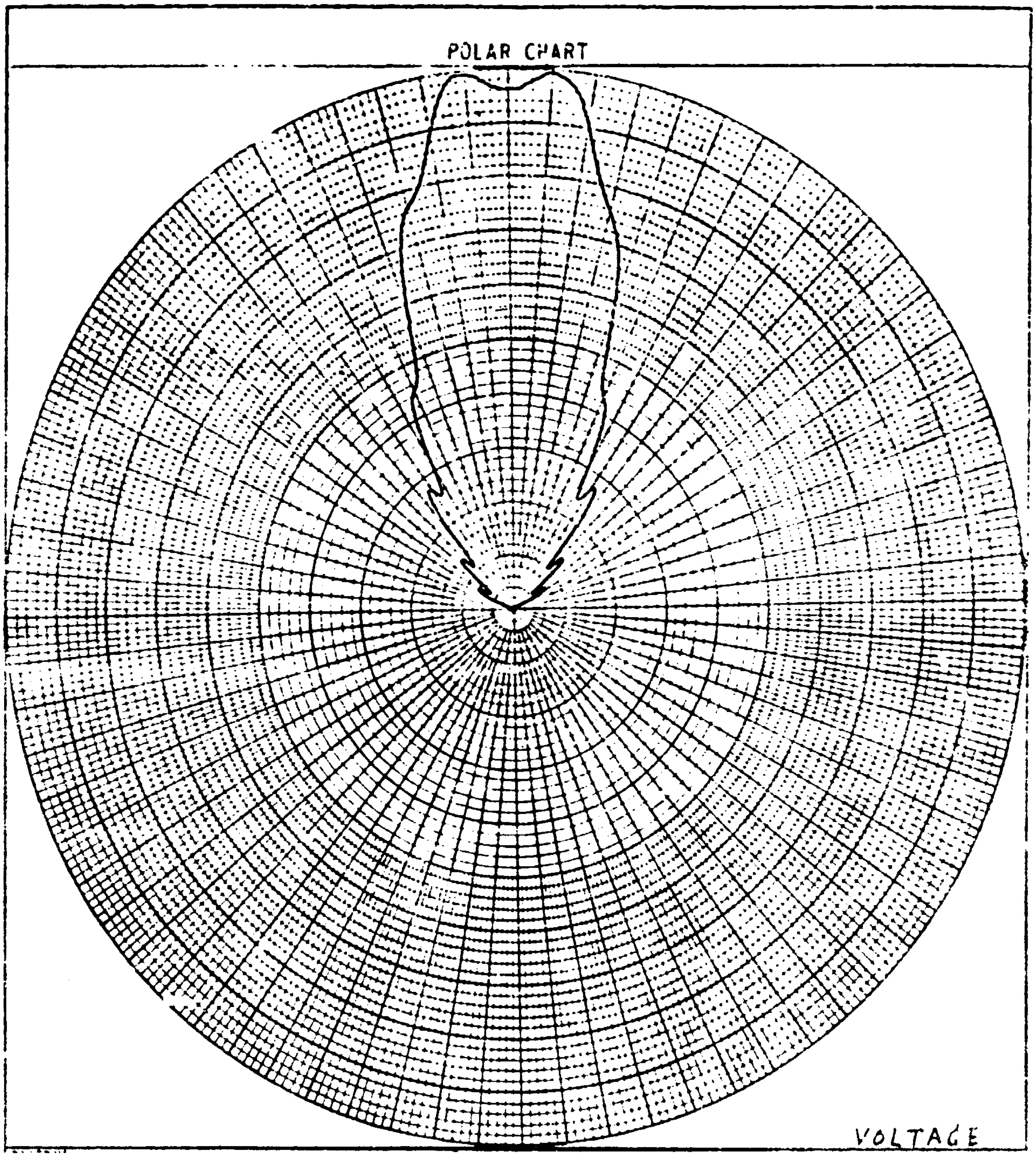
MODERATE-GAIN HORN

FIGURE 59 7.0 GHz E-PLANE



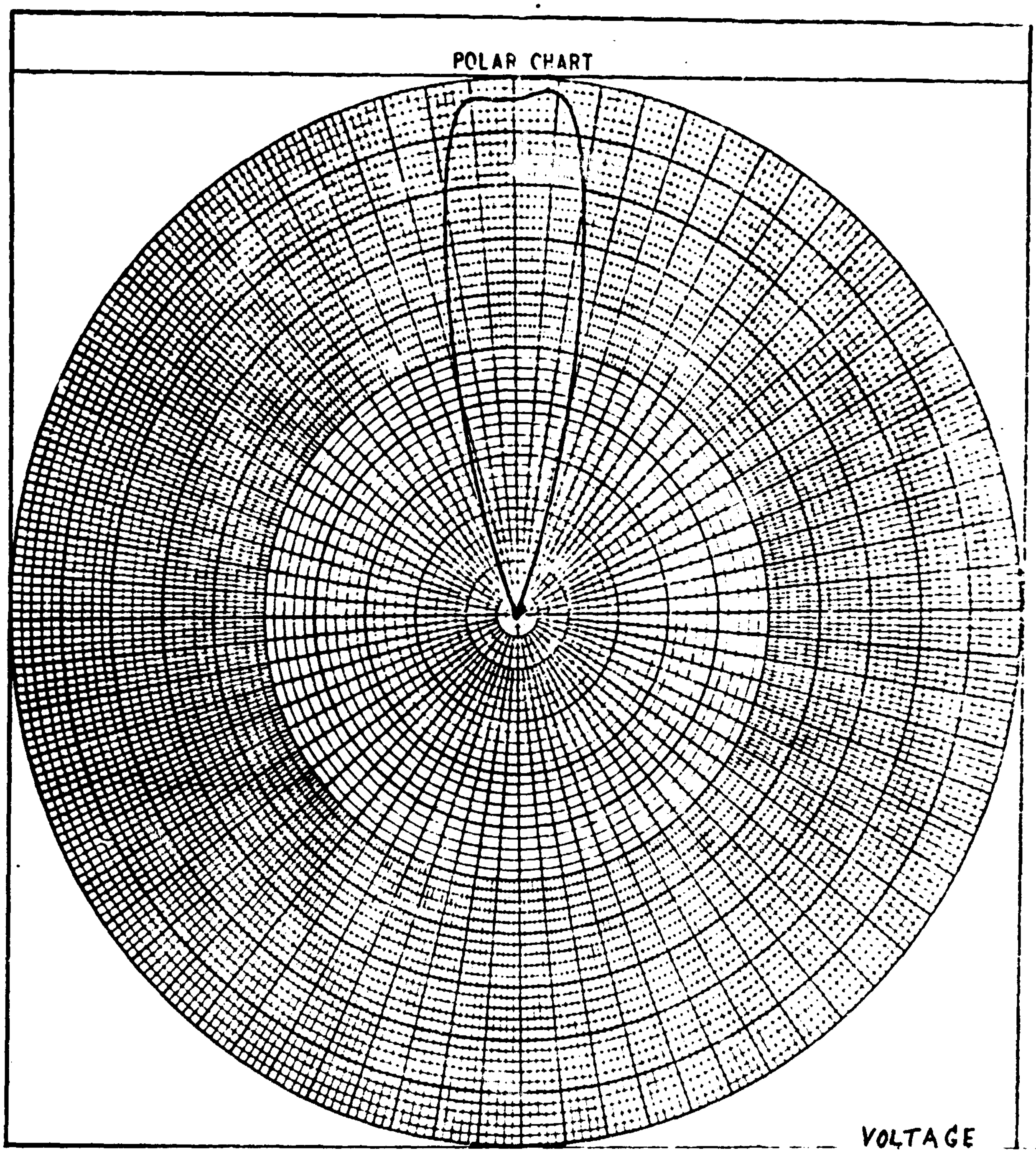
MODERATE-GAIN HORN

FIGURE 60 7.0 GHz H-PLANE



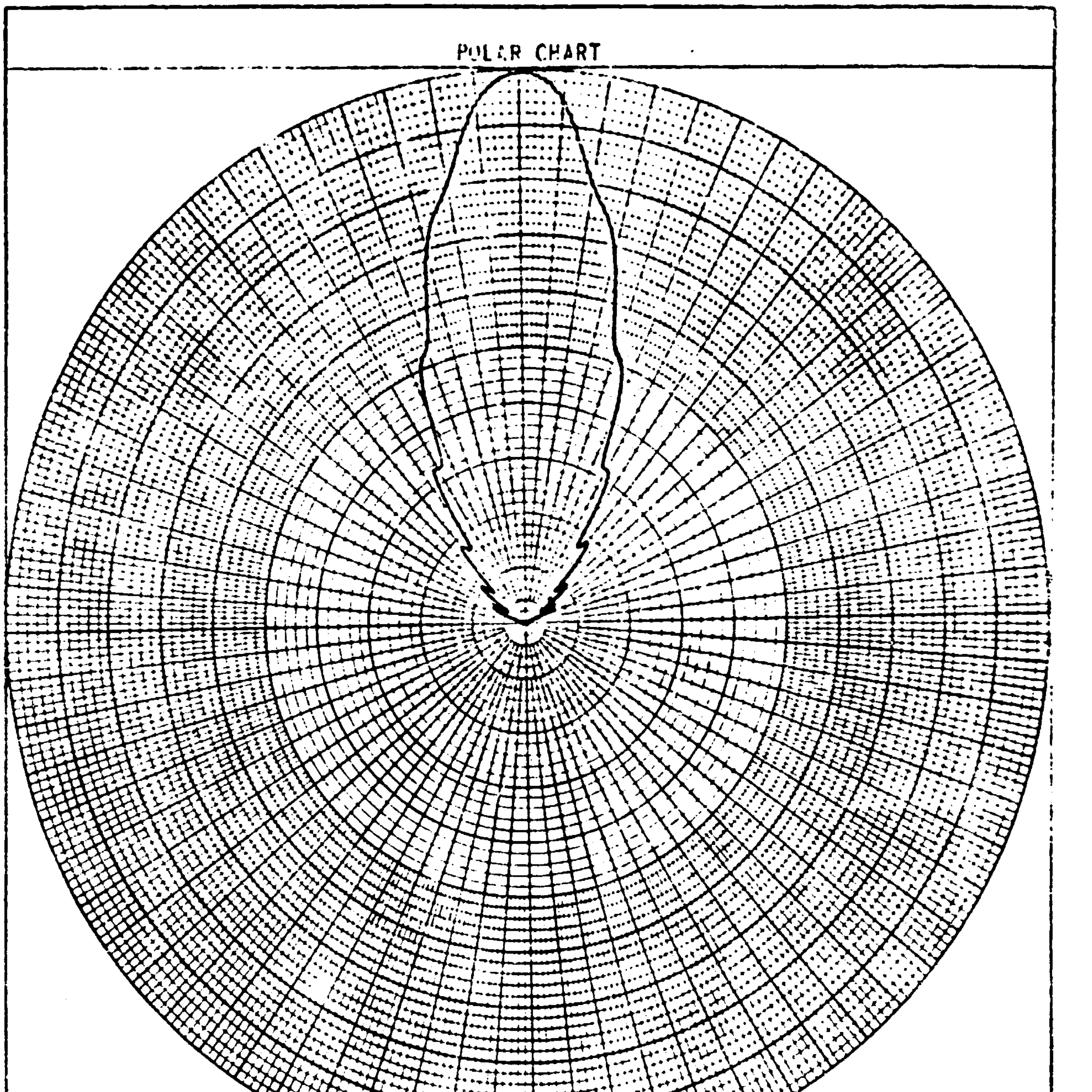
MODERATE-GAIN HORN

FIGURE 61   8.0 GHz E-PLANE



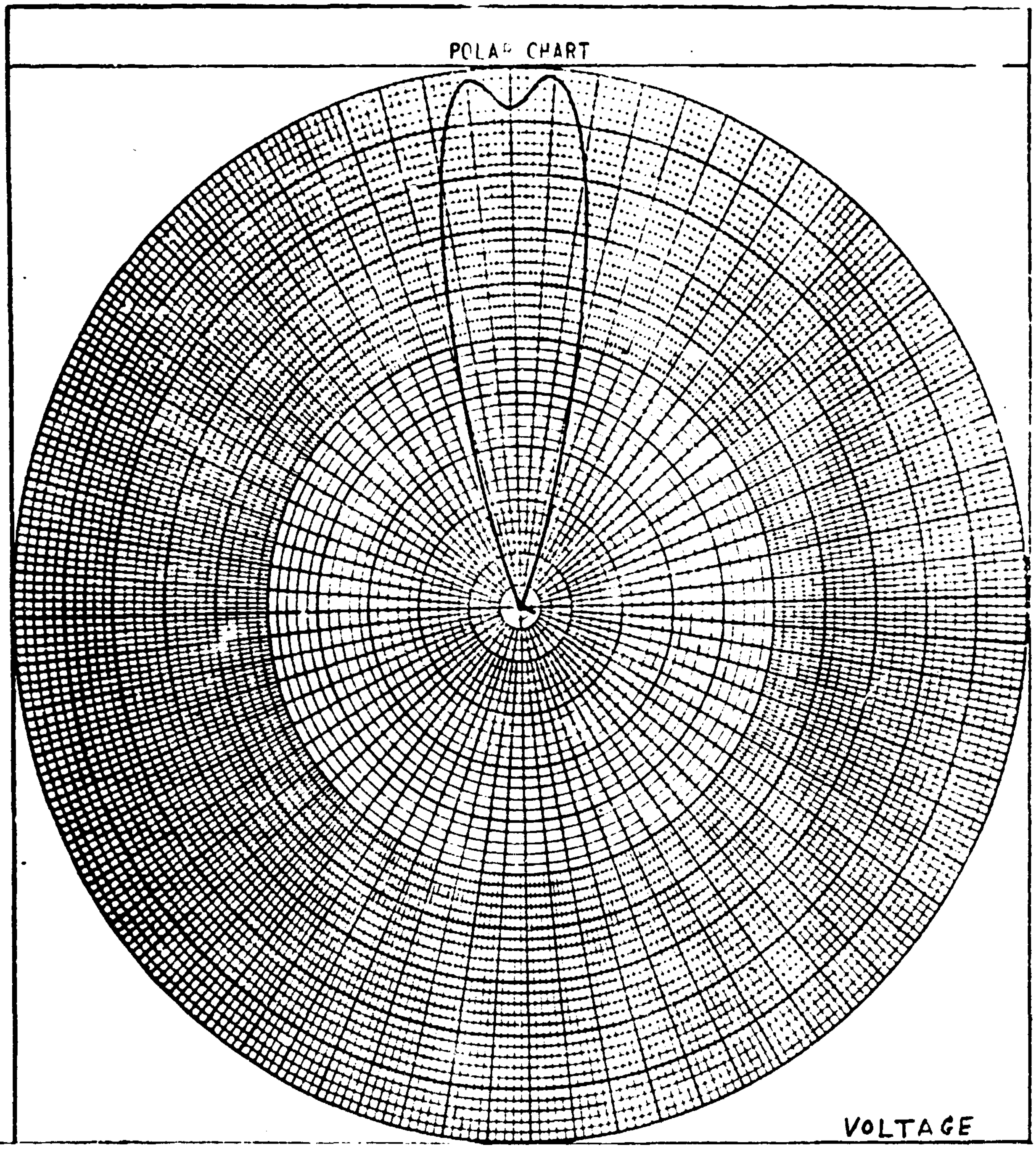
MODERATE-GAIN HORN

FIGURE 62 8.0 GHz H-PLANE



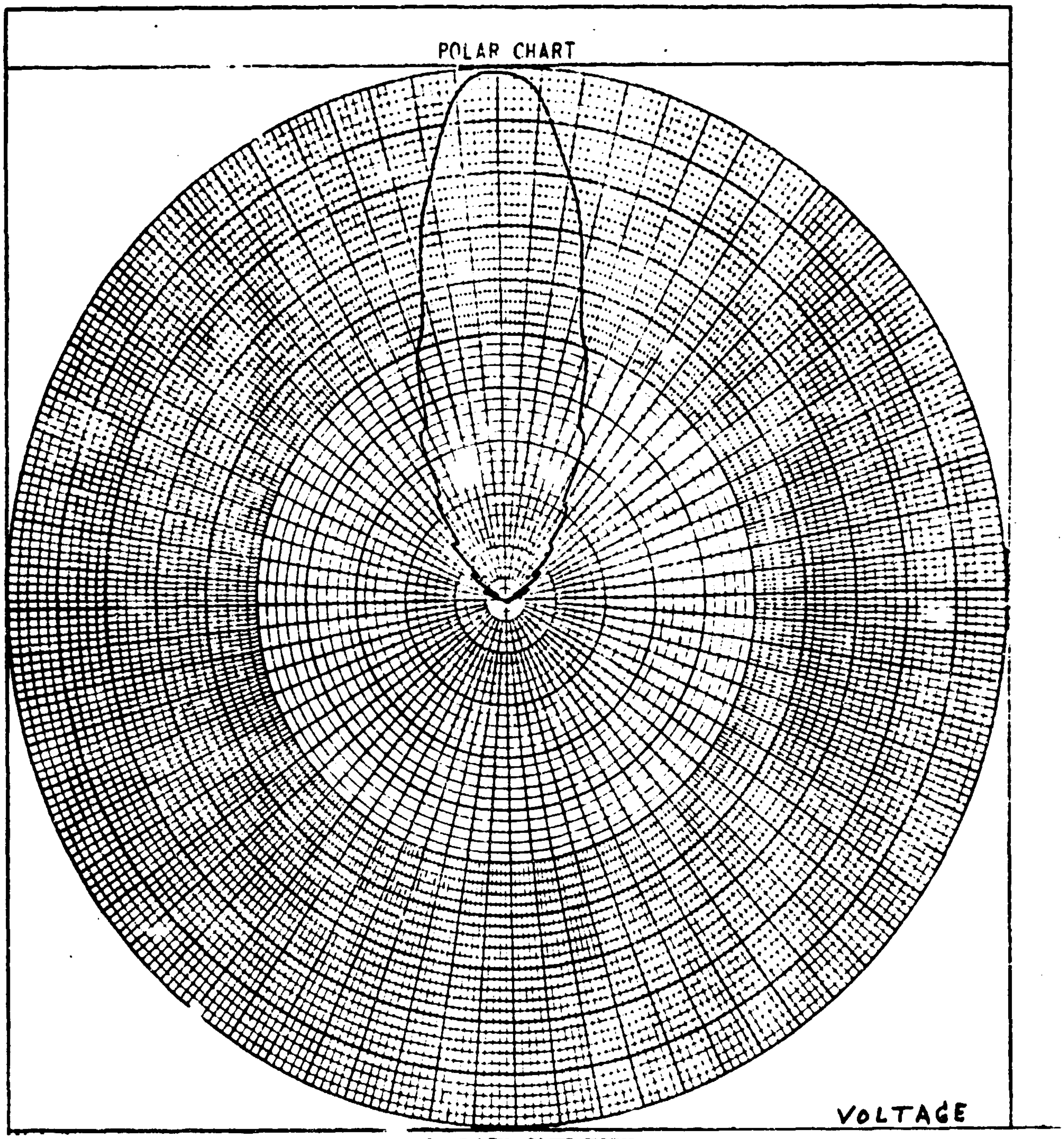
MODERATE-GAIN HORN

FIGURE 63 9.0 GHz E-PLANE



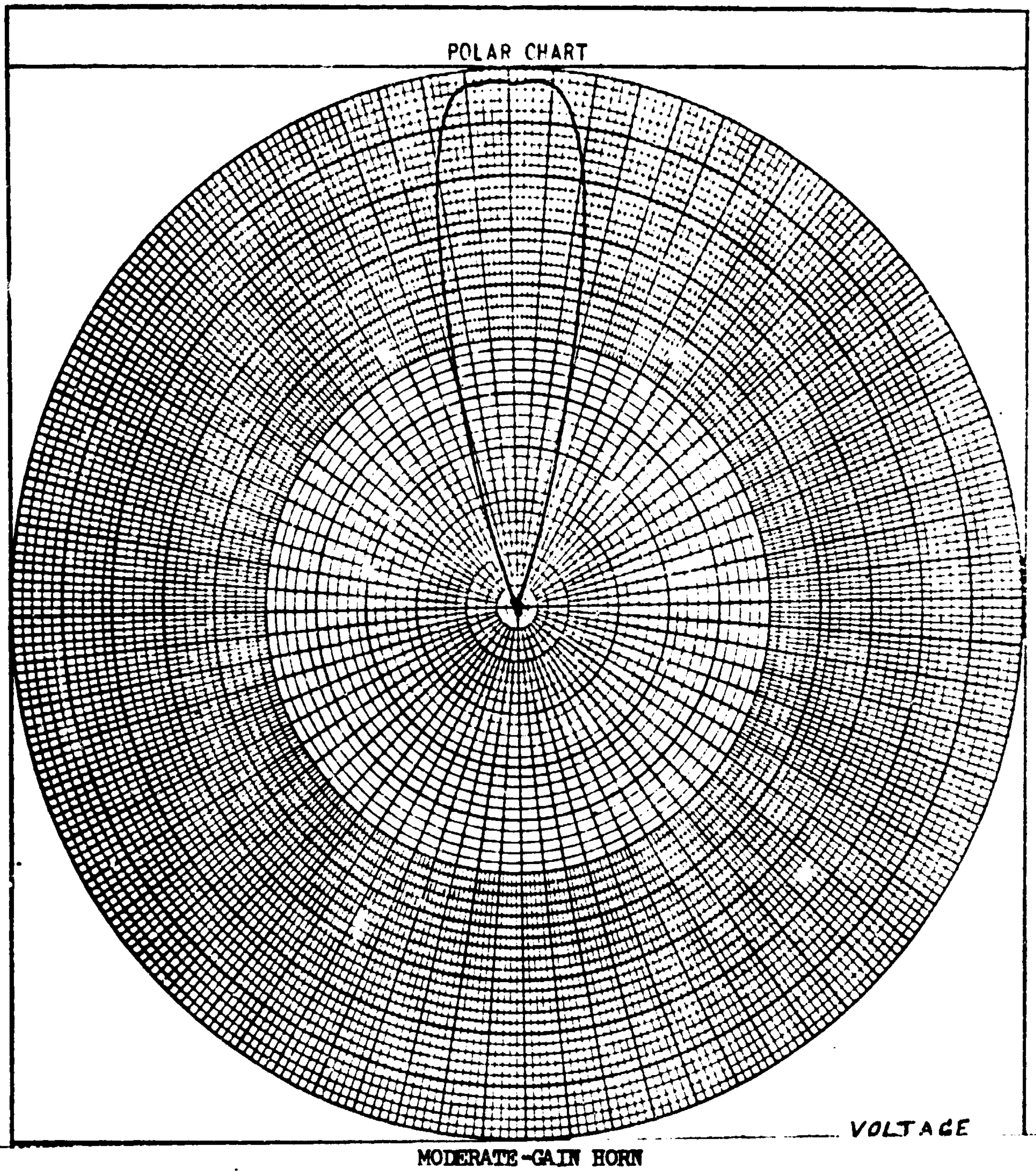
MODERATE-GAIN HORN

FIGURE 64 9.0 GHz H-PLANE



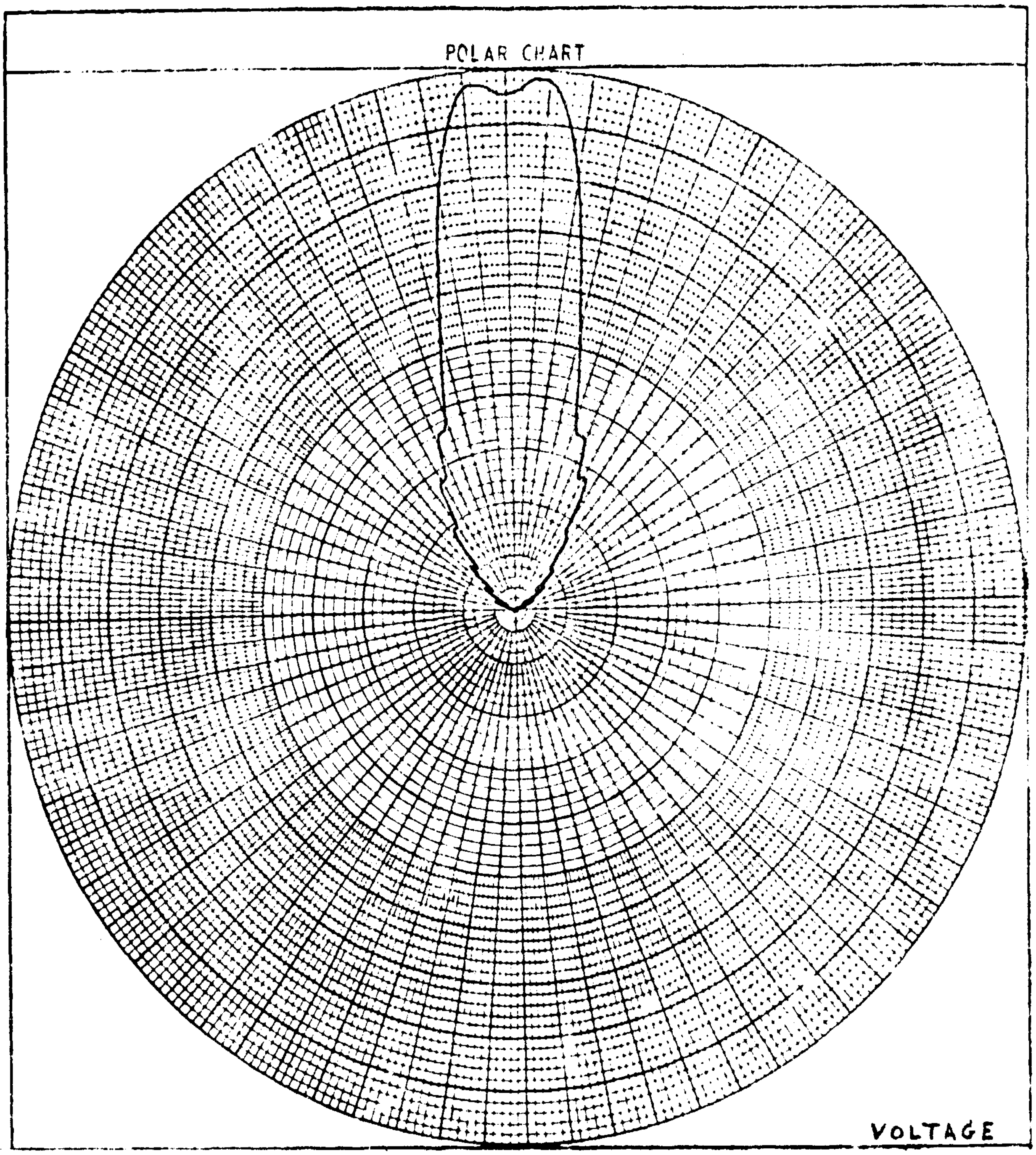
MODERATE-GAIN HORN

FIGURE 65 10.0 GHz E-PLANE



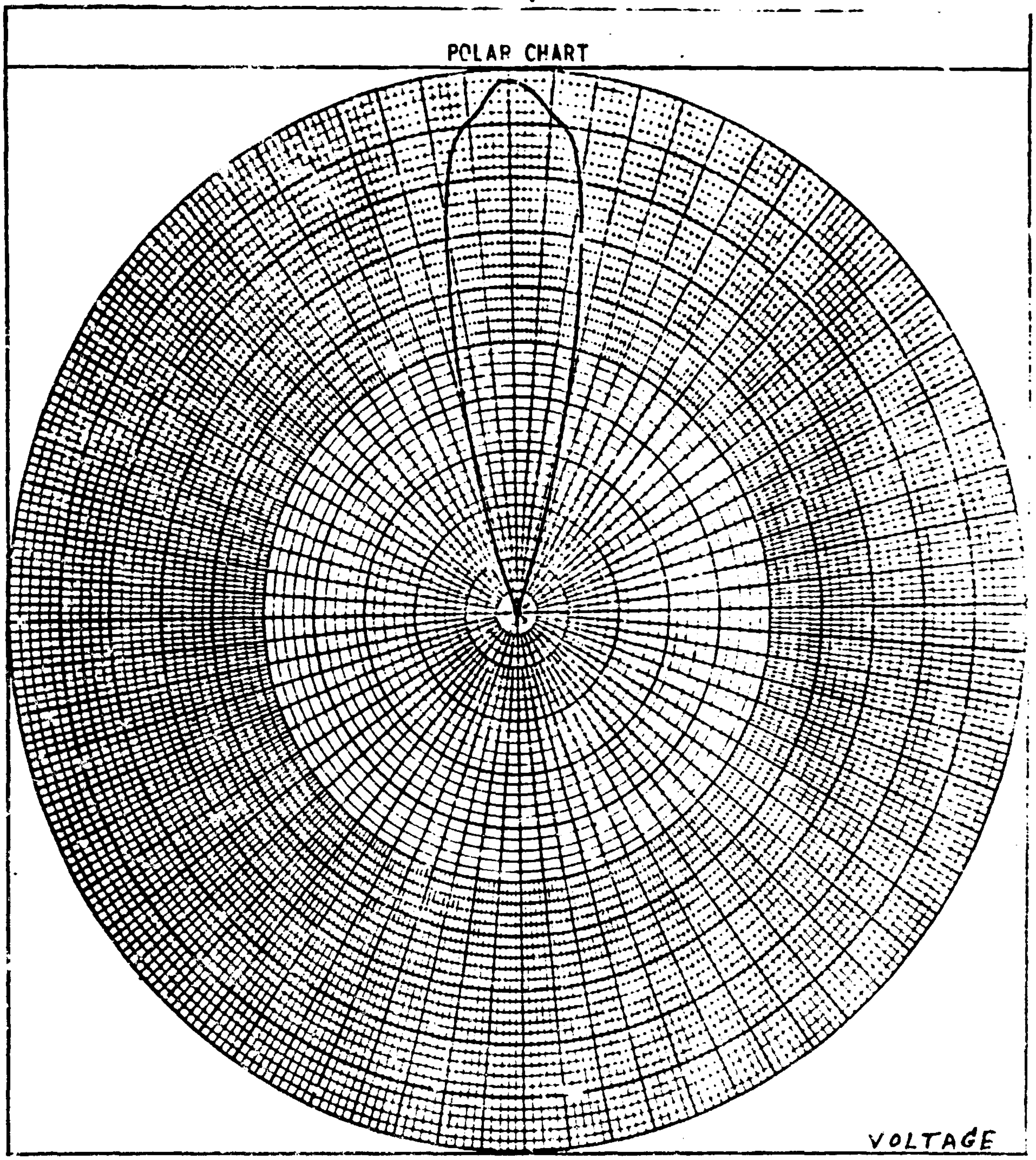
MODERATE-GAIN HORN

FIGURE 66 10.0 GHz H-PLANE



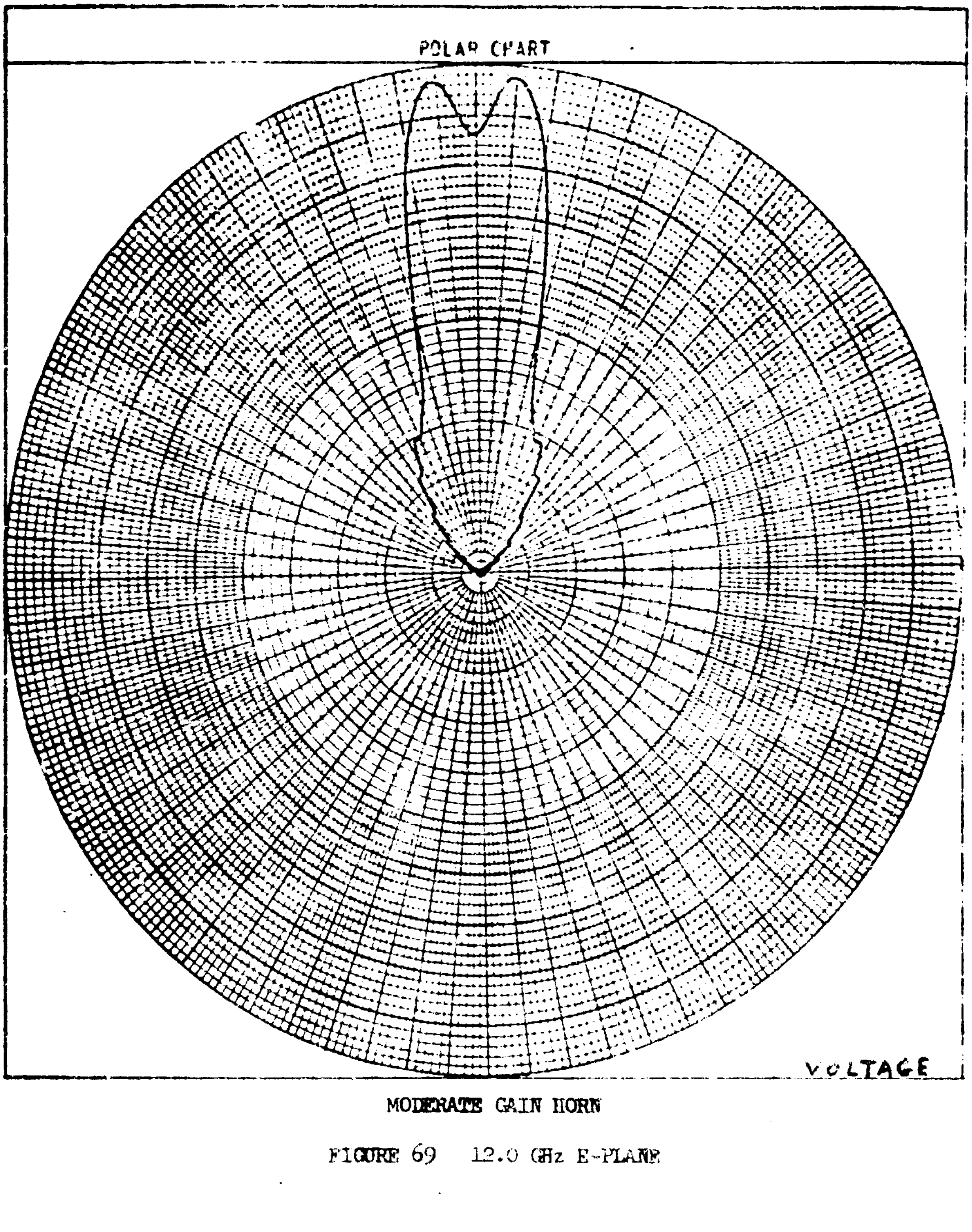
MODERATE-GAIN HORN

FIGURE 67 11.0 GHz E-PLANE



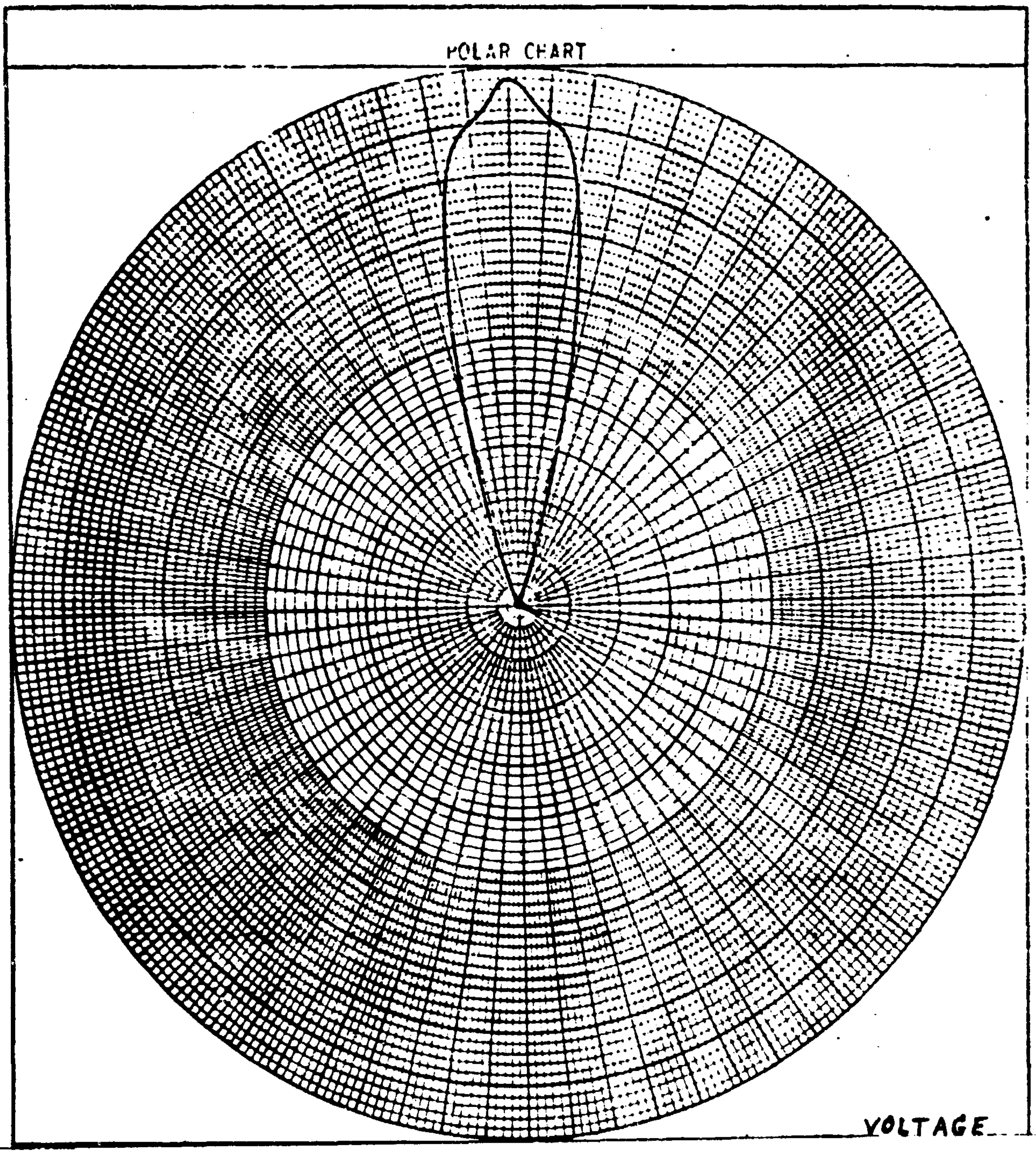
MODERATE-GAIN HORN

FIGURE 68 11.0 GHz H-PLANE



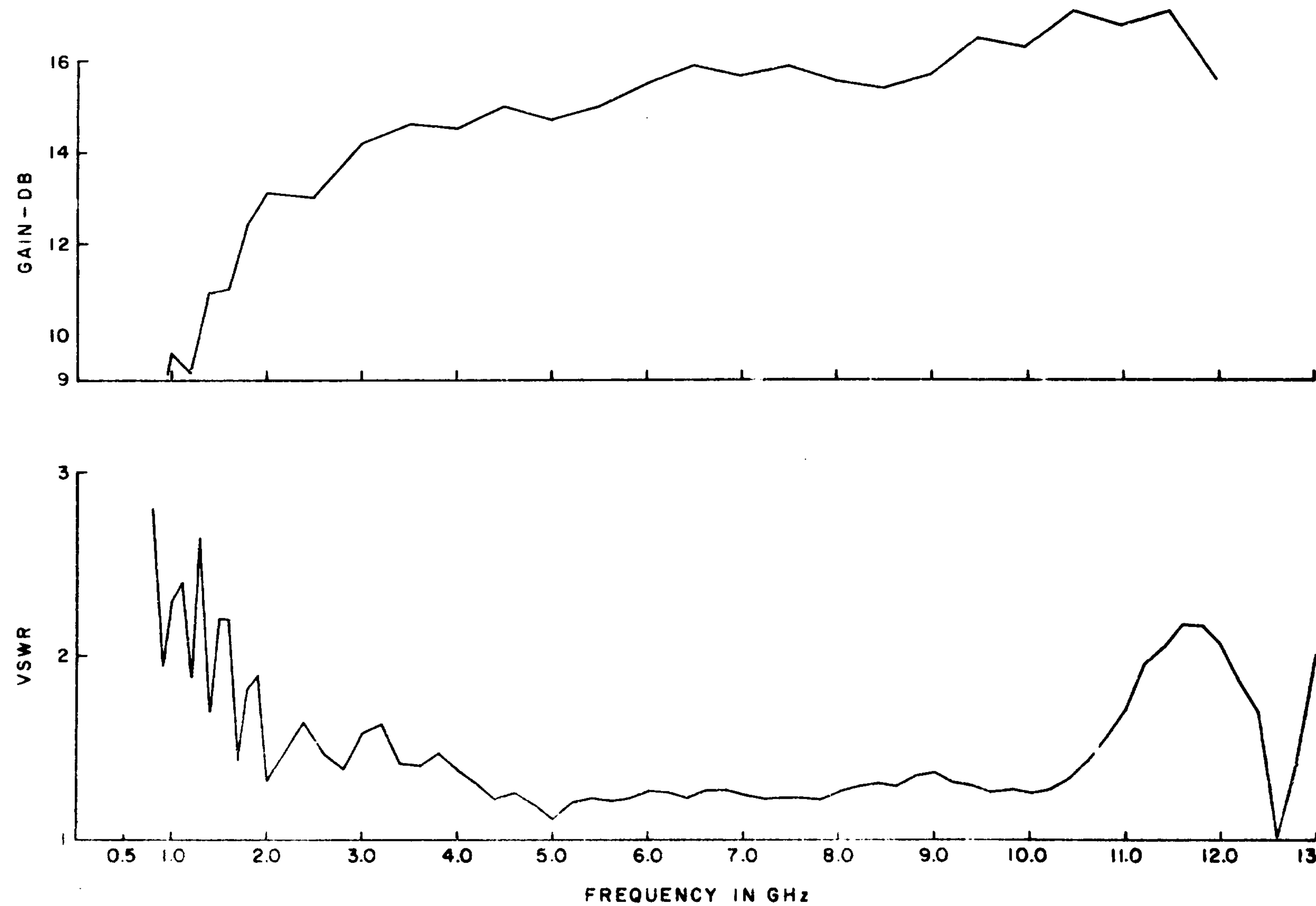
MODERATE GAIN HORN

FIGURE 69 12.0 GHz E-PLANE



MODERATE-GAIN HORN

FIGURE 70 12.0 GHz H-PLANE



MODERATE-GAIN HORN

FIGURE 71 VSWR & GAIN

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13. ABSTRACT

This report describes the development of two very broadband horn antennas using double-ridged waveguide techniques. The first design accomplished was that of a feed horn to be used to illuminate a six-foot parabolic reflector over the frequency range from 1 GHz to 12 GHz. Pattern data show that the beamwidth of this horn design rapidly becomes narrower than would normally be considered acceptable for that purpose. However, that was considered to be useful for the intended application since it was required that the half-power beamwidth from the six-foot parabola not become less than two degrees. That indicates that only about one half of the reflector should be illuminated at the upper frequency limit.

The second development consisted of designing a larger horn with a nominal gain of approximately 15 db and with a significant requirement that the gain variation be held to a minimum over the frequency range. The technique used to reduce the gain variation consisted of using relatively large flare angles to introduce increasingly greater phase error with increasing frequency and thus reduce the aperture efficiency.

Electrical performance characteristics are presented for the two horn designs as well as data measured with the feed horn illuminating a six-foot parabolic reflector.

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